NPS-67-82-011

NAVAL POSTGRADUATE SCHOOL

Monterey, California

A COMPUTER PROGRAM TO CALCULATE
IN-PLANE AND FLEXURAL PROPERTIES
OF SYMMETRIC LAMINATES ON THE
HP-87 MICROCOMPUTER

LCDR Dennis R. Ferrell

September 1982

Approved for public release; distribution unlimited.

Prepared for:

Dr. Stephen Tsai
AFWAL/MLBM
Wright Patterson AFB, OH 45433

NAVAL POSTGRADUATE SCHOOL
Monterey, California

Rear Admiral J.J. Ekelund
Superintendent

David A. Schrady
Provost

The work reported herein was conducted under the auspices of AE4103, Advanced Aircraft Construction, at the Naval Postgraduate School.

This report was prepared by:

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NPS-67-82-011	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A COMPUTER PROGRAM TO CALCULATE IN-PLANE AND FLEXURAL PROPERTIES OF SYMMETRIC LAMINATES ON THE HP-87 MICROCOMPUTER		5. TYPE OF REPORT & PERIOD COVERED Technical September 1982
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) LCDR Dennis R. Ferrell		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, CA 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Department of Aeronautics Naval Postgraduate School Monterey, CA 93940		12. REPORT DATE 30 September 1982
		13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Composites	Compliance
Laminates	HP-87
In-Plane	Basic Computer Language
Flexural	
Modulus	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The computation of parameters for symmetric laminates involves series of tedious calculations for both in-plane and flexural properties. In order to alleviate the magnitude and complexity of calculations for complicated symmetric laminates, the program of this report was designed for a commercially available microcomputer, the Hewlett-Packard HP-87, and is based for the most part on program logic developed by the Air Force Wright

20. ABSTRACT (continued)

Aeronautical Laboratories for the TI-59 handheld programmable calculator. Program logic is explained in detail with flowcharts and a full listing of the program is included. A description of the program logic provides the user with a comprehensive explanation of program operation.

ABSTRACT

The computation of parameters for symmetric laminates involves series of tedious calculations for both in-plane and flexural properties. In order to alleviate the magnitude and complexity of calculations for complicated symmetric laminates, the program of this report was designed for a commercially available microcomputer, the Hewlett-Packard HP-87, and is based for the most part on program logic developed by the Air Force Wright Aeronautical Laboratories for the TI-59 handheld programmable calculator. Program logic is explained in detail with flowcharts and a full listing of the program is included. A description of the program logic provides the user with a comprehensive explanation of program operation.

TABLE OF CONTENTS

Chapter I
INTRODUCTION

The program of this report is based on class work performed during the Summer Quarter 1982 at the Naval Postgraduate School and taught by Dr. Stephen W. Tsai of the Air Force Wright Aeronautical Laboratories. The original program was based on reference 1 and was written in order to compute and observe a variety of in-plane and flexural parameters calculated for symmetric laminates. Upon completion of that program, however, it was enhanced by the addition of subroutines and displays to compute the max stress and strain strength ratios in addition to quadratic strength ratios.

Chapter II explains program logic based on the flow charts of Appendix A. The reader will find that no special programming techniques were required and all calculations are straight forward.

There are two basic advantages to having a program such as this on a microcompter. First, although a microcomputer such as the HP-87 is obviously not as portable as a handheld calculator, the user will note distinct advantages to being able to view labeled output and matrices several lines at a time as opposed to single line, unlabeled output. Secondly, the program code is very easy to read and modify if necessary.

This program is not intended to be all encompassing, but it should be of assistance to users designing symmetric laminates. Users are encouraged to modify the program to suit their own needs and to publish addendum and erratta to this report. Corrections and modifications should be addressed to Dr. Tsai at AFWAL/MLBM, Wright-Patterson AFB, Ohio.

Chapter II
PROGRAM LOGIC

Even though this program has been written for the HP-87, modifications to fit this program on other microcomputers should not be difficult. The only really unique aspect of the program occurs during the initial parts of the program. Refer to the flowcharts of Appendix A.

A basic familiarity with the HP-87 is assumed. Load the program from disk storage, then initiate program operation with the RUN key. The program will prompt the user to signify if printer output is desired or not. Reply with Y or N. The program code is set for a printer address of 701. Ensure the printer has this address, or list the program code and change the address in line 60.

The HP-87 allows a programmer to set up 14 predefined keys for selective branching. In this program, selections are established for each of five commonly used laminate materials: T300/5208, B(4)/5505, AS/3501, SP1002, and KV49/EPOXY. Selection of any one of these five automatically inserts engineering constants into appropriate variable names. The units of these variables are in the SI system. Users desiring to work in English units need only select the

"SI -> ENG" key prior to selecting a material. A "flag variable" is set to unity for later logic testing to determine whether or not to apply a conversion factor to each of the input variables.

Users desiring to define their own material may do so by selecting "User Def'd". The program will prompt for a material name and each of the engineering constants before continuing.

The "Reference" key selects a display with an abbreviated explanation of the program, a list of the references, and author information. Press CONTINUE to return to the material selection display.

Unit ply thickness, ho, is then requested. Ensure that the dimension of this parameter is the same as that of the previous variables.

Following this, and in several subsequent locations, the user can choose to display computed variables or to bypass the display. If a printer is used with the program, prompts for variables and displays will not appear on the CRT, but will appear on the printer instead. Refer back and forth between the two to determine what the next input should be. With a printer connected, only a question mark will appear on the CRT. First time users are encouraged to use only the

CRT display (no printer) in order to get used to answering prompts and observing output. Run time for a complete series of calculations requires only a few minutes. Errors should be handled by stopping program operation with the PAUSE key, then reinitialize with the RUN key. Effort has been expended to make this program as user "friendly" as possible. Most prompts are self explanatory.

Following optional displays of modulus and compliance matrices as well as strength parameters, the program will signify that computation of in-plane variables are now progressing. A prompt for CORE/NO CORE laminates is then displayed. CORE laminates are those comprised of a honeycomb sandwich section placed on the centerline that contributes little to the stiffness of the laminate but is used to alter the weight characteristics. The thickness of the core is usually input as an integral multiple of the ply thickness.[1] Proper input of ply information in sequential order is very important for flexural properties later in the program. CORE and NO CORE materials both require ply information to be entered from the center ply outward in consecutive order. No attempt has been made to group ply

---

[1] A non-integral multiple for core thickness, nc, may be entered, but the initial ply index number, ti, will still have to be entered as an integer. Use the nearest multiple rounded off to the next highest number. Slight errors may occur, but they should be significant only for laminates with a relatively thick unit ply thickness.

orientations, and the user will be required to enter each ply. Programming was simplified by this expediency, but users entering complicated laminates or laminates with many plies may find it somewhat tedious. Feedback from the printer is immediate, however, so any mistakes may be discovered quickly.

Following input of CORE/NO CORE information, the in-plane modulus of laminates, Aij, is computed followed by its inverse, aij. Normalized versions of these matrices, Aij* and aij*, are computed as well as the effective in-plane engineering constants. A display of these variables is optional.

The program then requests input of loads (stress resultants) N1, N2, and N6, followed by a request for the orientation of the ply to be examined. Variables computed from these inputs include the in-plane strain variables, on-axis strain and stress variables, max stress-strain strength ratios (R/R'), and quadratic strength ratios (R/R'). A non-optional display lists results of these calculations. Following the display, the user can enter a new load and orientation and repeat the calculations and display. If a new load/orientation is not desired, the program proceeds to flexural computations.

Without further prompts, the program computes the flexural modulus matrix, Dij, followed by its inverse, dij. And in a manner similar to in-plane computations, normalized parameters, Dij* and dij*, are computed as well as effective flexural moduli, Eif. A display of these parameters is optional.

The program now prompts for the moments, M1, M2, and M6. An index number, t, representing the sequential ply number for the ply to be examined (counting from the ply closest to the center line) is requested along with the orientation of that ply. With these inputs, the program calculates curvature, ki, on-axis stress-strain, max stress-strain strength ratios (R & R'), and quadratic strength ratios (R & R'). A non-optional display presents all parameters in a format similar to that for in-plane parameters.

Following the display, the user can enter a new set of moments, index t, and THETAt for a repeat of the calculations. Selecting the other option terminates program operation.

Chapter III
SAMPLE CALCULATIONS

The following pages are reproduced from sample calculations generated by the LAMINATE program. The first program run displays all optional displays. Subsequent program runs delete many of these displays since T300/5208 was used for all calculations and many of these displays would not vary. The ply designations for each composite are noted next to the title for each run. The printer used for these runs was configured for a laterally compressed mode to allow for report format.

Many of the prompts do not appear on these print outs. The program is written to display many of the prompts only on the CRT. The reader is referred to the flowcharts to resolve questions about program operation a specific points.

COMPUTATION OF IN-PLANE AND FLEXURAL PROPERTIES OF SYMMETRIC
LAMINATES ON THE HP-87 MICROCOMPUTER

Selected composite material => T300/5208 $[0/90]_s$

Input laminate thickness, ho (SI or ENG).

ho = .000125

****

Engineering constants and compressive, tensile, and shear
constants for T300/5208

```
 Ex = 181.000E+009
 Ey =  10.300E+009
 vx =    .28
 Es =   7.170E+009

  X = 1500.000E+006
 X' = 1500.000E+006
  Y =   40.000E+006
 Y' =  246.000E+006
  S =   68.000E+006
```

****

```
********************************************************************************

On-axis Qij's, Sij's, UiQ's, Aij's, and aij's for T300/5208
(Note:  ij=xys).


               ( 181.81E+009  2.8969E+009      0
   on-axis Qij = (            10.346E+009      0
               (                           7.1700E+009

               ( 5.5249E-012  -1.547E-012      0
   on-axis Sij = (            97.087E-012      0
               (                           139.47E-012

         U1Q = 76.3682E+009
         U2Q = 85.7325E+009
         U3Q = 19.7104E+009
         U4Q = 22.6074E+009
         U5Q = 26.8804E+009

               ( 22.726E+006  .36212E+006      0
   on-axis Aij = (            1.2933E+006      0
               (                           .89625E+006

               ( 44.199E-009  -12.37E-009      0
   on-axis aij = (            776.70E-009      0
               (                           1120.8E-009

********************************************************************************


********************************************************************************

Strength parameters in stress space, Fij, and strain space, Gij.
for T300/5208 (Note:  ij=xys).


             ( .44444E-018  -3.360E-018      0
         Fij = (            101.63E-018      0
             (                           216.26E-018

          Fx = 00.000E-001
          Fy = 20.935E-009



             ( 12.004E+003  -3.069E+003      0
         Gij = (            10.681E+003      0
             (                           11.118E+003

          Gx = 6.0647E+001
          Gy = 2.1660E+002

********************************************************************************
```

```
********************************************************************************
********************************************************************************

The program will now compute in-plane and flexural properties of
laminates specified by the user.  Either CORE or NO CORE laminates
can be specified and any number of plies defined.  The user will
note that this program takes a 'brute force' approach by request-
ing an entry for each ply.  This method allows simpler program
code, ensures fewer errors, and enhances accuracy.

********************************************************************************
********************************************************************************

In-plane computations follow...

Will the laminate contain CORE or NO CORE?
   C/NC => END LINE



NO CORE laminate:  Enter 'n', the total number
of plies, surface to surface.
   n = ?

n = 4



NO CORE laminate thickness, h = .0005


 Now enter the ply orientation of each ply:
THETA(1), THETA(2), ... , THETA(n/2)
 *** --> FROM CENTER TO OUTER SURFACE <-- ***  (IMPORTANT!)



   THETA( 1 ) = ?

                  90

   THETA( 2 ) = ?

                  0
```

```
******************************************************************************

In-plane parameters:  Aij's, aij's, engineering constants, and
normalized Aij*'s and aij*'s for T300/5208  (Note:  ij=126)


                 ( 48.039E+006  1.4485E+006  8.4343E-006
   in-plane Aij = (             48.039E+006  2.0144E-004
                 (                           3.5850E+006

                 ( 20.835E-009  -.6282E-009  -.1371E-019
   in-plane aij = (             20.835E-009  -.1169E-017
                 (                           2.7894E-007

          E1o = 9.5991E+010
          E2o = 9.5991E+010
         v21o = .03015
          E6o = 7.1700E+009

                 ( 9.6079E+010  2.8969E+009  1.6869E-002
  in-plane Aij* = (             9.6079E+010  4.0288E-001
                 (                           7.1700E+009

                 ( 1.0418E-011  -.3141E-012  -.6859E-023
  in-plane aij* = (             1.0418E-011  -.5846E-021
                 (                           1.3947E-010

******************************************************************************


Input loads N1,N2,N6


N1 = 1    N2 = 0    N6 = 0


Now, enter THETAt, the orientation of the ply
to be examined (in degrees).
   THETAt = ?


THETAt = 0
```

```
********************************************************************************

         in-plane strain: e1o = 20.835E-009
                          e2o = -.6282E-009
                          e6o = -.1371E-019

For THETAt = 0  ....  (T300/5208)

                on-axis strain: exo = 2.0835E-008
                                eyo = -6.282E-010
                                eso = -.1371E-019

                on-axis stress: sxo = 37.863E+002
                                syo = 53.858E+000
                                sso = -.9836E-010


         strength ratios        R           R'

            max strain    3.99E+005   3.98E+005
            max stress    3.96E+005   3.96E+005
            quadratic     3.41E+005   5.54E+005

                average stresses: sto = 6.8188E+008
                                  sto' = 1.1077E+009
                      (=f(quadratic R & R'))

********************************************************************************


New load:  N1 = 1    N2 = 0    N6 = 0



Now, enter THETAt, the orientation of the ply
to be examined (in degrees).
   THETAt = ?


THETAt = 90
```

```
********************************************************************************

        in-plane strain: e1o = 20.835E-009
                         e2o = -.6282E-009
                         e6o = -.1371E-019

For THETAt = 90  ....  (T300/5208)

              on-axis strain: exo = -.6282E-009
                              eyo = 20.835E-009
                              eso = -.1964E-018

              on-axis stress: sxo = -5.385E+001
                              syo = 21.374E+001
                              sso = -.1408E-008


        strength ratios        R           R'

             max strain    1.86E+005   1.15E+006
             max stress    1.87E+005   1.15E+006
             quadratic     1.87E+005   1.13E+006

              average stresses: sto = 3.7340E+008
                                sto' = 2.2688E+009
                           (=f(quadratic R & R'))

********************************************************************************


********************************************************************************
********************************************************************************

The program will now compute flexural properties for the laminate
defined during the in-plane definitions.  Properties calculated
include the flexural stiffness matrix (Dij), the flexural compli-
ance matrix (dij), effective flexural laminate moduli (Eif), and
the normalized versions of stiffness matrices (Dij* and dij*).

********************************************************************************
********************************************************************************
```

```
********************************************************************************

Flexural properties Dij, dij, effective flexural engineering
constants, and the normalized Dij* and dij*. (Note: ij=126)

                  ( 1.6706E+000  .30176E-001  4.3929E-014
   flexural Dij = (              3.3103E-001  1.0492E-012
                  (                           7.4688E-002

                  ( 5.9957E-001  -.5465E-001  4.1512E-013
   flexural dij = (              3.0258E+000  -.4247E-010
                  (                           1.3389E+001

           E1f = 1.6011E+011
           E2f =  3.1727E+010
          v21f =   .09116
           E6f = 7.1700E+009

                  ( 1.6038E+011  2.8969E+009  4.2171E-003
  flexural Dij* = (              3.1779E+010  1.0072E-001
                  (                           7.1700E+009

                  ( 6.2456E-012  -.5693E-012  4.3241E-024
  flexural dij* = (              3.1519E-011  -.4424E-021
                  (                           1.3947E-010

********************************************************************************


Input moments M1,M2,M6


M1 = 1    M2 = 0    M6 = 0


Now, enter the index number, t, and the orientation, THETAt,
of the ply to be examined.
   t, THETAt = ?


t = 2    THETAt = 0
```

```
********************************************************************************

         curvature, k1 = 5.9957E-001
                    k2 = -.5465E-001
                    k6 = 4.1512E-013

For t = 2 and THETAt = 0

    flex'l strains, e1f = 1.4989E-004
                    e2f = -.1366E-004
                    e6f = 1.0378E-016

   flex'l stresses, s1f = 2.7213E+007
                    s2f = 2.9286E+005
                    s6f = 7.4410E-007

strength ratios        R           R'

     max strain    5.53E+001   5.53E+001
     max stress    5.51E+001   5.51E+001
     quadratic     4.95E+001   7.11E+001

                    average stresses: sto = 1.1880E+009
                                      sto' = 1.7056E+009
                              (=f(quadratic R & R'))

********************************************************************************


Input new loads M1,M2,M6


New moments:  M1 = 1    M2 = 0    M6 = 0


Now, enter the index number, t, and the orientation, THETAt,
of the ply to be examined.
   t, THETAt = ?


t = 1    THETAt = 90
```

```
********************************************************************************

        curvature, k1 = 5.9957E-001
                   k2 = -.5465E-001
                   k6 = 4.1512E-013

For t = 1 and THETAt = 90

   flex'l strains, e1f = 7.4947E-005
                   e2f = -.6832E-005
                   e6f = 5.1890E-017

   flex'l stresses, s1f = 7.5562E+005
                    s2f = -.1025E+007
                    s6f = -.5132E-005

strength ratios         R           R'

     max strain    5.18E+001   3.19E+002
     max stress    5.29E+001   3.26E+002
     quadratic     5.22E+001   3.01E+002

                   average stresses: sto = 1.2535E+009
                                     sto' = 7.2139E+009
                          (=f(quadratic R & R'))

********************************************************************************


End of program.  Thank you.
```

COMPUTATION OF IN-PLANE AND FLEXURAL PROPERTIES OF SYMMETRIC
LAMINATES ON THE HP-87 MICROCOMPUTER

Selected composite material =) T300/5208

$$\left[0_2/90_2/45_2/-45_2\right]_s$$

Input laminate thickness, ho (SI or ENG).

ho = .000125

```
******************************************************************************
******************************************************************************
```

The program will now compute in-plane and flexural properties of laminates specified by the user. Either CORE or NO CORE laminates can be specified and any number of plies defined. The user will note that this program takes a 'brute force' approach by requesting an entry for each ply. This method allows simpler program code, ensures fewer errors, and enhances accuracy.

```
******************************************************************************
******************************************************************************
```

In-plane computations follow...

Will the laminate contain CORE or NO CORE?
   C/NC =) END LINE

NO CORE laminate: Enter 'n', the total number
of plies, surface to surface.
   n = ?

```
n = 16



NO CORE laminate thickness, h = .002


Now enter the ply orientation of each ply:
THETA(1), THETA(2), ... , THETA(n/2)
*** --> FROM CENTER TO OUTER SURFACE <-- ***  (IMPORTANT!)



   THETA( 1 ) = ?

                    -45

   THETA( 2 ) = ?

                    -45

   THETA( 3 ) = ?

                     45

   THETA( 4 ) = ?

                     45

   THETA( 5 ) = ?

                     90

   THETA( 6 ) = ?

                     90

   THETA( 7 ) = ?

                     0

   THETA( 8 ) = ?

                     0
```

```
*******************************************************************************

In-plane parameters:  Aij's, aij's, engineering constants, and
normalized Aij*'s and aij*'s for T300/5208  (Note:  ij=126)


               ( 15.274E+007  4.5215E+007  1.6869E-005
   in-plane Aij = (             15.274E+007  4.0288E-004
               (                          5.3761E+007

               ( 71.761E-010  -.2124E-008  1.3668E-020
   in-plane aij = (             71.761E-010  -.5311E-019
               (                          1.8601E-008

          E1o = 6.9676E+010
          E2o = 6.9676E+010
         v21o = .29603
          E6o = 2.6880E+010

               ( 7.6368E+010  2.2607E+010  8.4343E-003
  in-plane Aij* = (             7.6368E+010  2.0144E-001
               (                          2.6880E+010

               ( 1.4352E-011  -.4248E-011  2.7336E-023
  in-plane aij* = (             1.4352E-011  -.1062E-021
               (                          3.7202E-011

*******************************************************************************


Input loads N1,N2,N6


N1 = 1    N2 = 0    N6 = 0


Now, enter THETAt, the orientation of the ply
to be examined (in degrees).
   THETAt = ?


THETAt = 45
```

```
********************************************************************************

         in-plane strain: e1o = 71.761E-010
                          e2o = -.2124E-008
                          e6o = 1.3668E-020

For THETAt = 45  ....  (T300/5208)

                 on-axis strain: exo = 2.5259E-009
                                 eyo = 25.259E-010
                                 eso = -.9300E-008

                 on-axis stress: sxo = 46.655E+001
                                 syo = 33.450E+000
                                 sso = -.6668E+002


         strength ratios        R            R'

              max strain    1.02E+006   1.02E+006
              max stress    1.02E+006   1.02E+006
              quadratic     6.94E+005   1.35E+006

                 average stresses: sto = 3.4700E+008
                                   sto' = 6.7508E+008
                          (=f(quadratic R & R'))

********************************************************************************


New load:  N1 = 1    N2 = 0    N6 = 0



Now, enter THETAt, the orientation of the ply
to be examined (in degrees).
   THETAt = ?


THETAt = 90
```

```
*********************************************************************************

        in-plane strain: e1o = 71.761E-010
                         e2o = -.2124E-008
                         e6o = 1.3668E-020

For THETAt = 90  ....  (T300/5208)

              on-axis strain: exo = -.2124E-008
                              eyo = 71.761E-010
                              eso = -.1047E-018

              on-axis stress: sxo = -3.654E+002
                              syo = 38.091E+000
                              sso = -.7509E-009


        strength ratios        R          R'

            max strain    5.41E+005   3.33E+006
            max stress    5.87E+005   3.61E+006
            quadratic     5.52E+005   2.60E+006

              average stresses: sto = 2.7612E+008
                                sto' = 1.2976E+009
                          (=f(quadratic R & R'))

*********************************************************************************


New load:  N1 = 1    N2 = 0    N6 = 0



Now, enter THETAt, the orientation of the ply
to be examined (in degrees).
   THETAt = ?


THETAt = 0
```

```
******************************************************************************

         in-plane strain: e1o = 71.761E-010
                          e2o = -.2124E-008
                          e6o = 1.3668E-020

For THETAt = 0  ....  (T300/5208)

                on-axis strain: exo = 7.1761E-009
                                eyo = -2.124E-009
                                eso = 1.3668E-020

                on-axis stress: sxo = 12.985E+002
                                syo = -1.190E+000
                                sso = 9.7999E-011


         strength ratios        R           R'

             max strain    1.15E+006   1.15E+006
             max stress    1.16E+006   1.16E+006
             quadratic     1.16E+006   1.13E+006

                  average stresses: sto = 5.8181E+008
                                    sto' = 5.6542E+008
                           (=f(quadratic R & R'))

******************************************************************************



******************************************************************************
******************************************************************************

The program will now compute flexural properties for the laminate
defined during the in-plane definitions.  Properties calculated
include the flexural stiffness matrix (Dij), the flexural compli-
ance matrix (dij), effective flexural laminate moduli (Eif), and
the normalized versions of stiffness matrices (Dij* and dij*).

******************************************************************************
******************************************************************************
```

```
********************************************************************************

Flexural properties Dij, dij, effective flexural engineering
constants, and the normalized Dij* and dij*.  (Note: ij=126)

                  ( 7.6842E+001  .52164E+001  2.6791E+000
    flexural Dij = (              4.4693E+001  2.6791E+000
                  (                           8.0651E+000

                  ( 1.3241E-002  -.1307E-002  -.3964E-002
    flexural dij = (              2.2959E-002  -.7192E-002
                  (                           1.2770E-001

          E1f = 1.1329E+011
          E2f =  6.5334E+010
          v21f =   .09877
          E6f = 1.1747E+010

                  ( 1.1526E+011  7.8245E+009  4.0187E+009
   flexural Dij* = (              6.7039E+010  4.0187E+009
                  (                           1.2098E+010

                  ( 8.8271E-012  -.8718E-012  -.2642E-011
   flexural dij* = (              1.5306E-011  -.4794E-011
                  (                           8.5132E-011

********************************************************************************


Input moments M1,M2,M6



M1 = 1    M2 = 0    M6 = 0


Now, enter the index number, t, and the orientation, THETAt,
of the ply to be examined.
    t, THETAt = ?




t = 8    THETAt = 0
```

```
******************************************************************************

        curvature, k1 = 1.3241E-002
                   k2 = -.1307E-002
                   k6 = -.3964E-002

For t = 8 and THETAt = 1

    flex'l strains, e1f = 1.3241E-005
                    e2f = -.1307E-005
                    e6f = -.3964E-005

   flex'l stresses, s1f = 2.4035E+006
                    s2f = 2.4827E+004
                    s6f = -.2842E+005

strength ratios        R           R'

     max strain    6.26E+002   6.26E+002
     max stress    6.24E+002   6.24E+002
     quadratic     5.46E+002   7.62E+002

                    average stresses: sto = 8.1881E+008
                                     sto' = 1.1431E+009
                          (=f(quadratic R & R'))

******************************************************************************


Input new loads M1,M2,M6


New moments:  M1 = 1    M2 = 0    M6 = 0


Now, enter the index number, t, and the orientation, THETAt,
of the ply to be examined.
    t, THETAt = ?


t = 6    THETAt = 90
```

```
********************************************************************************

        curvature, k1 = 1.3241E-002
                   k2 = -.1307E-002
                   k6 = -.3964E-002

For t = 6 and THETAt = 90

    flex'l strains, e1f = 9.9305E-006
                    e2f = -.9808E-006
                    e6f = -.2973E-005

   flex'l stresses, s1f = 9.9901E+004
                    s2f = -.1495E+006
                    s6f = -.2131E+005

strength ratios        R           R'

     max strain    3.91E+002   2.41E+003
     max stress    4.00E+002   2.46E+003
     quadratic     3.89E+002   2.10E+003

                   average stresses: sto = 5.8418E+008
                                     sto' = 3.1496E+009
                         (=f(quadratic R & R'))

********************************************************************************


Input new loads M1,M2,M6


New moments:  M1 = 1    M2 = 0    M6 = 0


Now, enter the index number, t, and the orientation, THETAt,
of the ply to be examined.
    t, THETAt = ?


t = 4    THETAt = 45
```

```
********************************************************************************

        curvature, k1 = 1.3241E-002
                   k2 = -.1307E-002
                   k6 = -.3964E-002

For t = 4 and THETAt = 45

   flex'l strains, e1f = 6.6203E-006
                   e2f = -.6538E-006
                   e6f = -.1982E-005

  flex'l stresses, s1f = 2.6246E+005
                   s2f = 1.5815E+005
                   s6f = -.2053E+006

strength ratios       R           R'

    max strain    9.77E+002   1.30E+003
    max stress    8.53E+002   1.30E+003
    quadratic     6.71E+002   1.97E+003

                   average stresses: sto = 1.0072E+009
                                     sto' = 2.9548E+009
                            (=f(quadratic R & R'))

********************************************************************************


End of program.  Thank you.
```

COMPUTATION OF IN-PLANE AND FLEXURAL PROPERTIES OF SYMMETRIC
LAMINATES ON THE HP-87 MICROCOMPUTER

Selected composite material => T300/5208

$$\left[0_2/90_2/45_2/-45_2/C_8\right]_s$$

Input laminate thickness, ho (SI or ENG).

ho = .000125

```
*********************************************************************************
*********************************************************************************
```

The program will now compute in-plane and flexural properties of laminates specified by the user. Either CORE or NO CORE laminates can be specified and any number of plies defined. The user will note that this program takes a 'brute force' approach by requesting an entry for each ply. This method allows simpler program code, ensures fewer errors, and enhances accuracy.

```
*********************************************************************************
*********************************************************************************
```

In-plane computations follow...

Will the laminate contain CORE or NO CORE?
   C/NC => END LINE

CORE laminate: Enter 'n', the total number of laminate plies, and 'nc', the total number of equivalent core plies that define its thickness, surface to surface.
   n,nc = ?

n = 16   nc = 16

CORE laminate thickness, h = .004

```
Counting outward from the center of the laminate, enter an
integer number 'ti' (t initial) that represents the consecutive
index number of the ply adjacent to the core.  (For instance,
if the core is a total of 4ho thick, count 2 equivalent ply layers
from the center so that ti=3).
   ti = ?


ti = 9


Now enter the ply orientation, in degrees, for each ply:
THETA(ti), THETA(ti+1) ... , THETA(n/2).
*** --) CENTER MOST PLY TO OUTER SURFACE PLY (-- ***  (IMPORTANT)

   THETA( 9 ) = ?

                    -45

   THETA( 10 ) = ?

                    -45

   THETA( 11 ) = ?

                    45

   THETA( 12 ) = ?

                    45

   THETA( 13 ) = ?

                    90

   THETA( 14 ) = ?

                    90

   THETA( 15 ) = ?

                    0

   THETA( 16 ) = ?

                    0
```

```
******************************************************************************

In-plane parameters:  Aij's, aij's, engineering constants, and
normalized Aij*'s and aij*'s for T300/5208  (Note:  ij=126)


                ( 15.274E+007  4.5215E+007  1.6869E-005
   in-plane Aij = (              15.274E+007  4.0288E-004
                (                           5.3761E+007

                ( 71.761E-010  -.2124E-008  1.3668E-020
   in-plane aij = (              71.761E-010  -.5311E-019
                (                           1.8601E-008

          E1o = 3.4838E+010
          E2o = 3.4838E+010
         v21o = .29603
          E6o = 1.3440E+010

                ( 3.8184E+010  1.1304E+010  4.2171E-003
  in-plane Aij* = (              3.8184E+010  1.0072E-001
                (                           1.3440E+010

                ( 2.8704E-011  -.8497E-011  5.4672E-023
  in-plane aij* = (              2.8704E-011  -.2124E-021
                (                           7.4404E-011

******************************************************************************


Input loads N1,N2,N6


N1 = 1    N2 = 0    N6 = 0


Now, enter THETAt, the orientation of the ply
to be examined (in degrees).
   THETAt = ?


THETAt = 45
```

****

in-plane strain: e1o = 71.761E-010
e2o = -.2124E-008
e6o = 1.3668E-020

For THETAt = 45 .... (T300/5208)

on-axis strain: exo = 2.5259E-009
eyo = 25.259E-010
eso = -.9300E-008

on-axis stress: sxo = 46.655E+001
syo = 33.450E+000
sso = -.6668E+002

strength ratios	R	R'
max strain	1.02E+006	1.02E+006
max stress	1.02E+006	1.02E+006
quadratic	6.94E+005	1.35E+006

average stresses: sto = 1.7350E+008
sto' = 3.3754E+008
(=f(quadratic R & R'))

****

****
****

The program will now compute flexural properties for the laminate defined during the in-plane definitions. Properties calculated include the flexural stiffness matrix (Dij), the flexural compliance matrix (dij), effective flexural laminate moduli (Eif), and the normalized versions of stiffness matrices (Dij* and dij*).

****
****

```
********************************************************************************

Flexural properties Dij, dij, effective flexural engineering
constants, and the normalized Dij* and dij*.  (Note: ij=126)

                  ( 4.2346E+002  .75935E+002  1.3396E+001
   flexural Dij = (              3.4844E+002  1.3396E+001
                  (                           9.5876E+001

                  ( 2.4645E-003  -.5266E-003  -.2707E-003
   flexural dij = (              2.9980E-003  -.3452E-003
                  (                           1.0516E-002

          E1f = 7.6080E+010
          E2f =  6.2542E+010
         v21f =   .21370
          E6f = 1.7830E+010

                  ( 7.9398E+010  1.4238E+010  2.5117E+009
  flexural Dij* = (              6.5333E+010  2.5117E+009
                  (                           1.7977E+010

                  ( 1.3144E-011  -.2808E-011  -.1444E-011
  flexural dij* = (              1.5989E-011  -.1841E-011
                  (                           5.6086E-011

********************************************************************************


Input moments M1,M2,M6


M1 = 1    M2 = 0    M6 = 0


Now  enter the index number, t, and the orientation, THETAt,
of the ply to be examined.
   t, THETAt = ?


t = 16    THETAt = 0
```

```
*******************************************************************************

         curvature, k1 = 2.4645E-003
                    k2 = -.5266E-003
                    k6 = -.2707E-003

For t = 16 and THETAt = 0

    flex'l strains, e1f = 4.9290E-006
                    e2f = -.1053E-005
                    e6f = -.5415E-006

   flex'l stresses, s1f = 8.9310E+005
                    s2f = 3.3809E+003
                    s6f = -.3682E+004

strength ratios        R           R'

     max strain    1.68E+003   1.68E+003
     max stress    1.68E+003   1.68E+003
     quadratic     1.62E+003   1.83E+003

                    average stresses: sto = 6.0642E+008
                                      sto' = 6.8480E+008
                              (=f(quadratic R & R'))

*******************************************************************************



Input new loads M1,M2,M6



New moments:  M1 = 1    M2 = 0    M6 = 0


Now, enter the index number, t, and the orientation, THETAt,
of the ply to be examined.
   t, THETAt = ?



t = 14    THETAt = 90
```

```
********************************************************************************

         curvature, k1 = 2.4645E-003
                    k2 = -.5266E-003
                    k6 = -.2707E-003

For t = 14 and THETAt = 90

   flex'l strains, e1f = 4.3129E-006
                   e2f = -.9216E-006
                   e6f = -.4738E-006

  flex'l stresses, s1f = 4.1952E+004
                   s2f = -.1550E+006
                   s6f = -.3397E+004

strength ratios        R           R'

    max strain    9.00E+002   5.54E+003
    max stress    9.53E+002   5.86E+003
    quadratic     9.14E+002   4.64E+003

                   average stresses: sto = 3.4294E+008
                                    sto' = 1.7398E+009
                              (=f(quadratic R & R'))

********************************************************************************


Input new loads M1,M2,M6


New moments:  M1 = 1    M2 = 0    M6 = 0


Now, enter the index number, t, and the orientation, THETAt,
of the ply to be examined.
   t, THETAt = ?



t = 12    THETAt = 45
```

```
********************************************************************************

         curvature, k1 = 2.4645E-003
                    k2 = -.5266E-003
                    k6 = -.2707E-003

For t = 12 and THETAt = 45

    flex'l strains, e1f = 3.6968E-006
                    e2f = -.7900E-006
                    e6f = -.4061E-006

   flex'l stresses, s1f = 1.5861E+005
                    s2f = 9.4270E+004
                    s6f = -.7019E+005

strength ratios        R           R'

     max strain    2.11E+003   2.11E+003
     max stress    1.73E+003   2.11E+003
     quadratic     1.30E+003   2.97E+003

                 average stresses: sto = 4.8649E+008
                                   sto' = 1.1153E+009
                         (=f(quadratic R & R'))

********************************************************************************


End of program.  Thank you.
```

Chapter IV
CONCLUSIONS

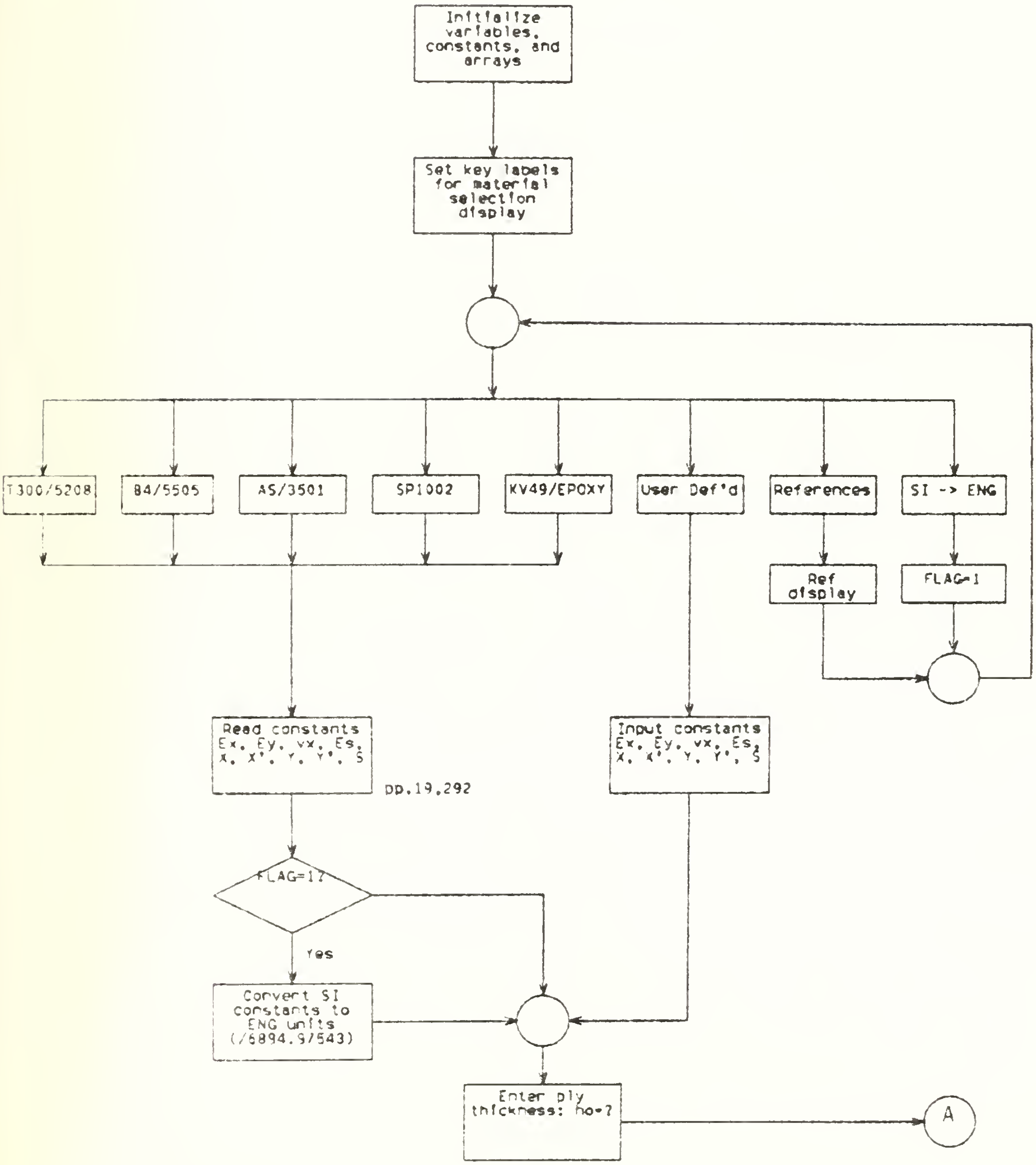
The original intent of this program was to duplicate and enhance the TI-59 program of reference 1 on a popularly available microcomputer. The HP-87 is a unit more than likely to find utility in many engineering organizations and it was the hope of the author to contribute to the design of laminates by automating many tedious calculations, presenting them in an easy to read format.

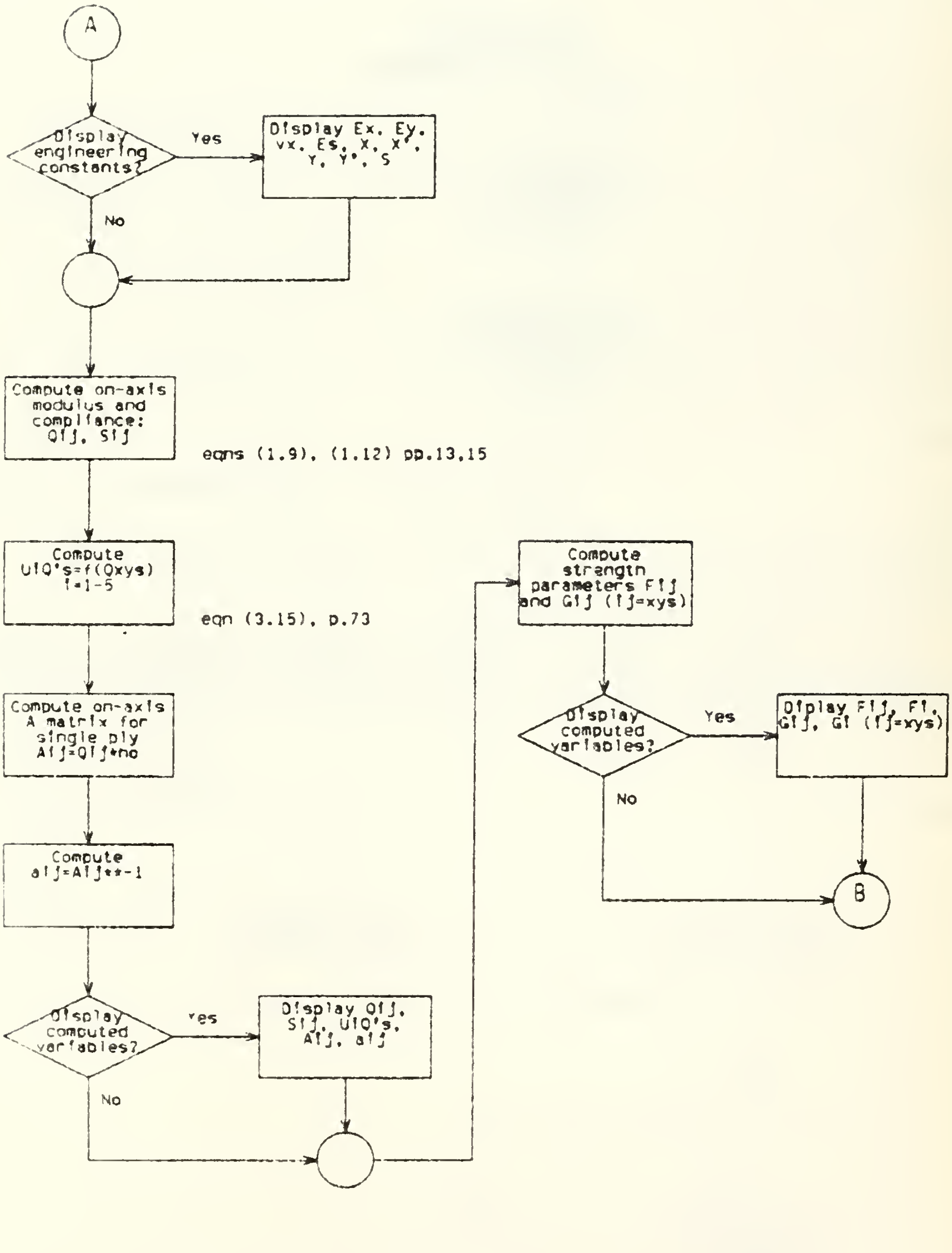
The program listing in Appendix B should allow quick and easy trouble shooting of any uncorrected programming errors. Modifications and additions should be relatively simple to program.

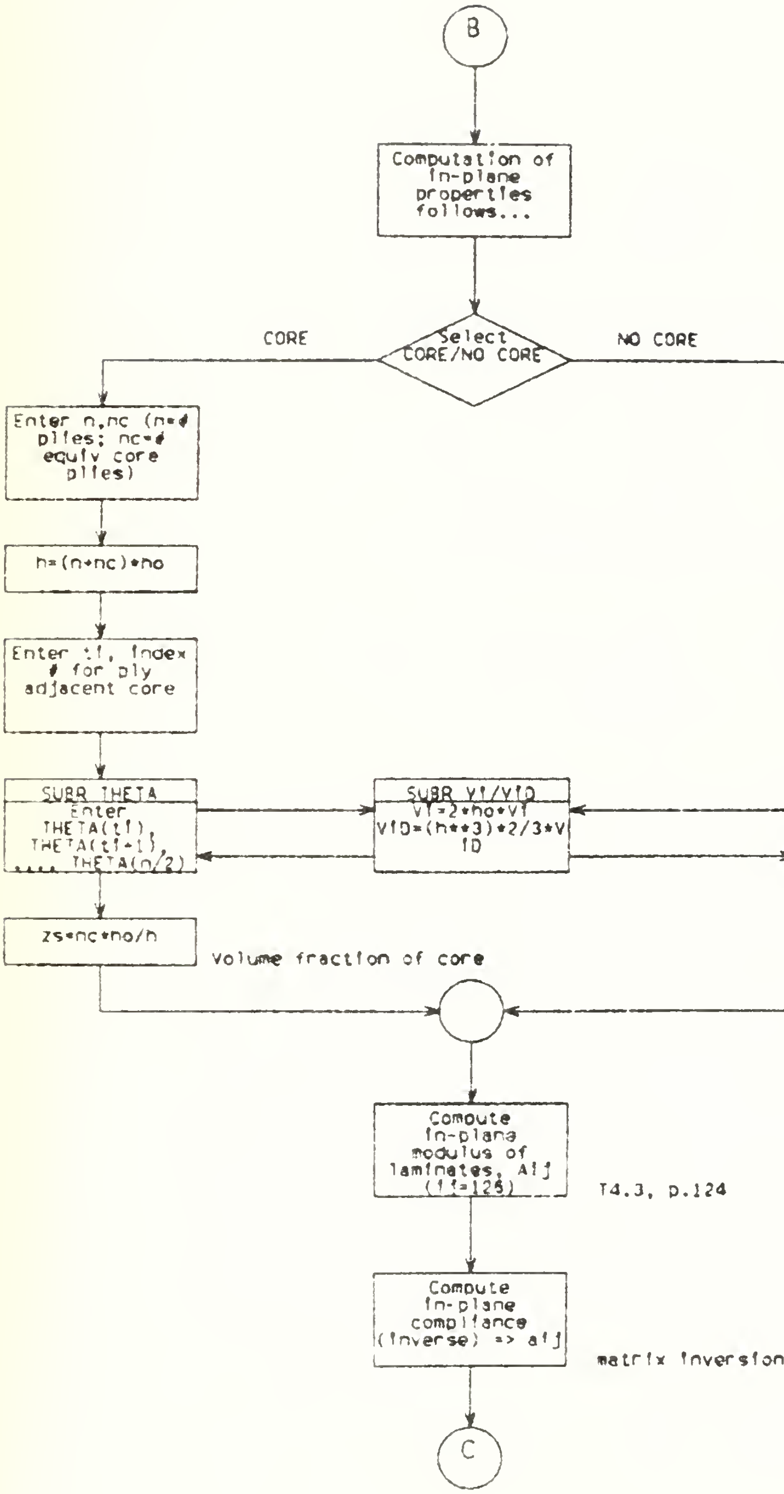
Overall, this program allows considerably more flexibility than the TI-59 program. It should also serve well as an educational tool for students and engineers desiring to review the theory of symmetric laminates.

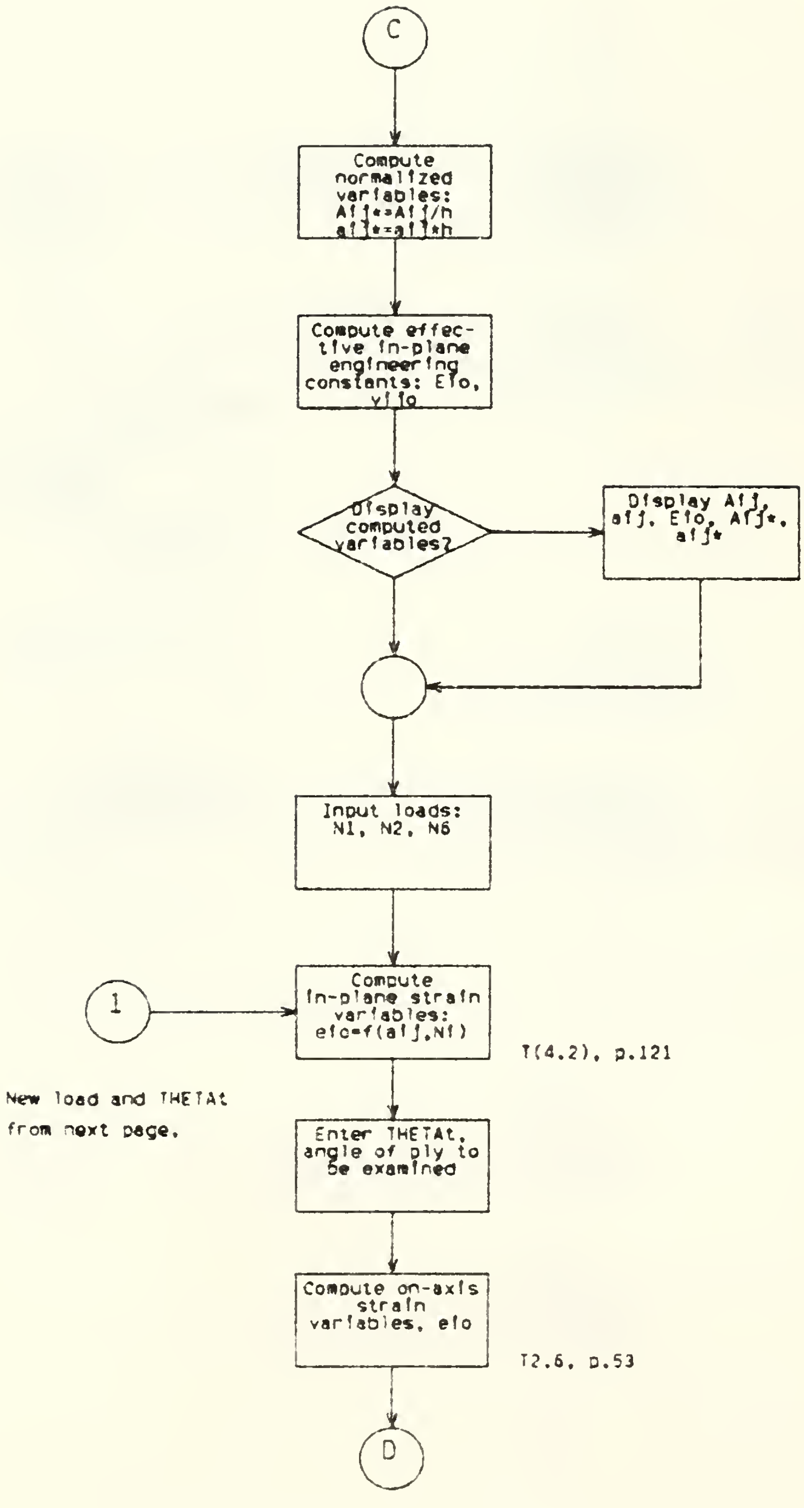
Appendix A

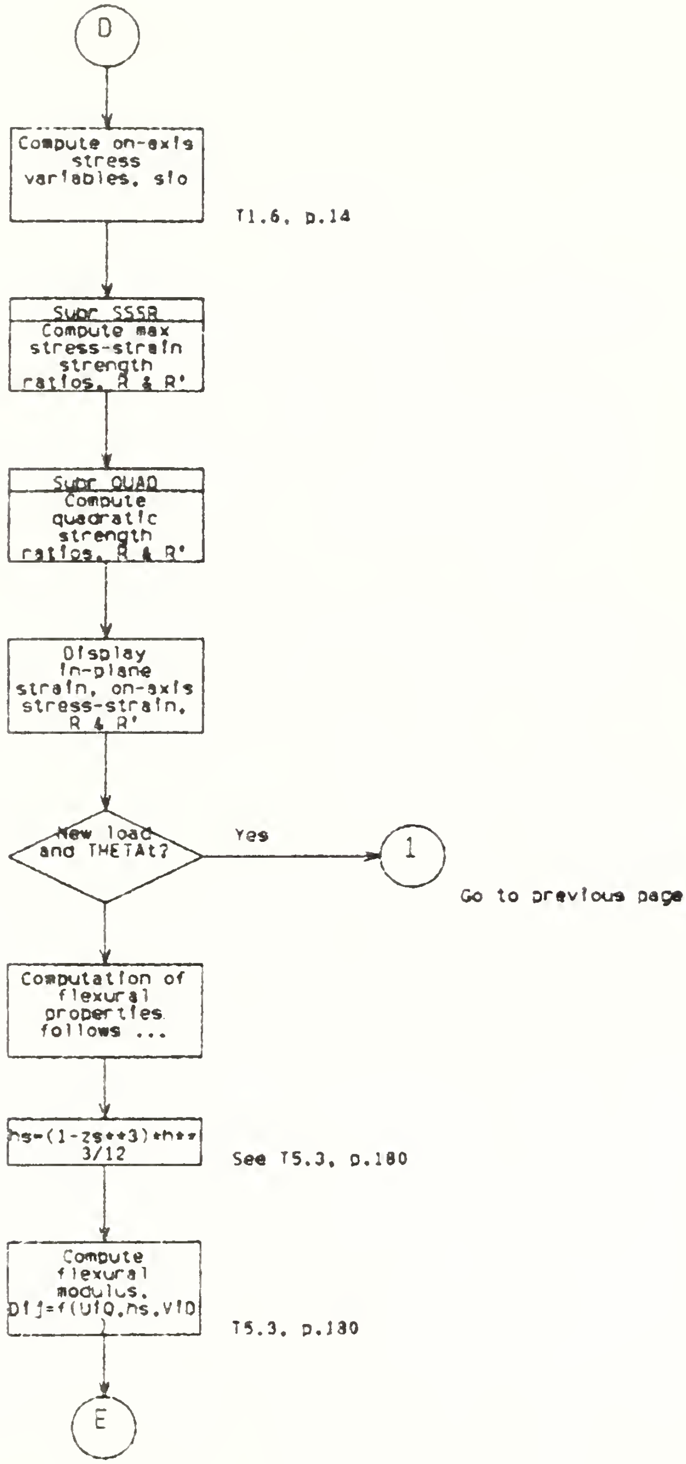
PROGRAM FLOWCHARTS

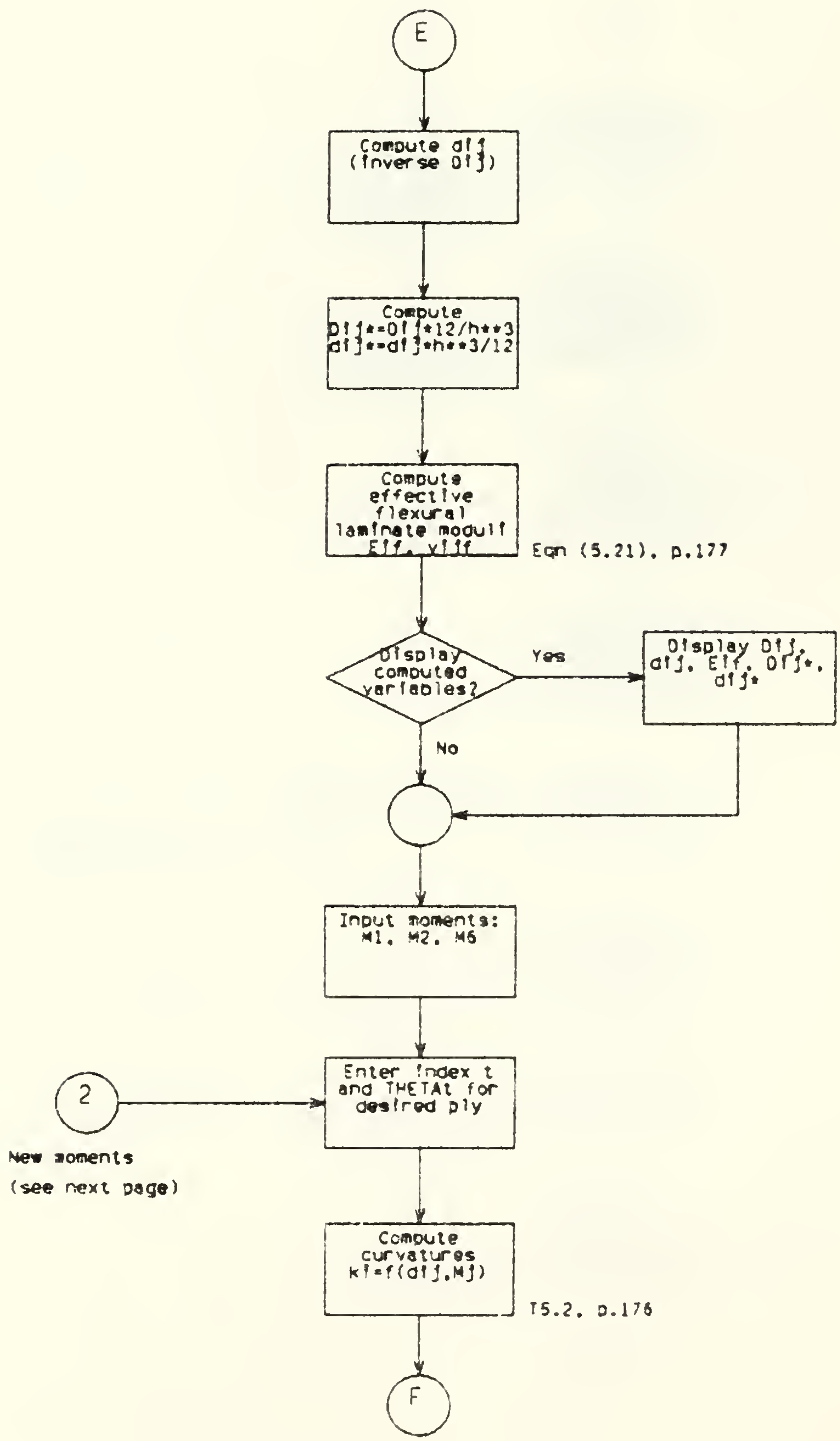


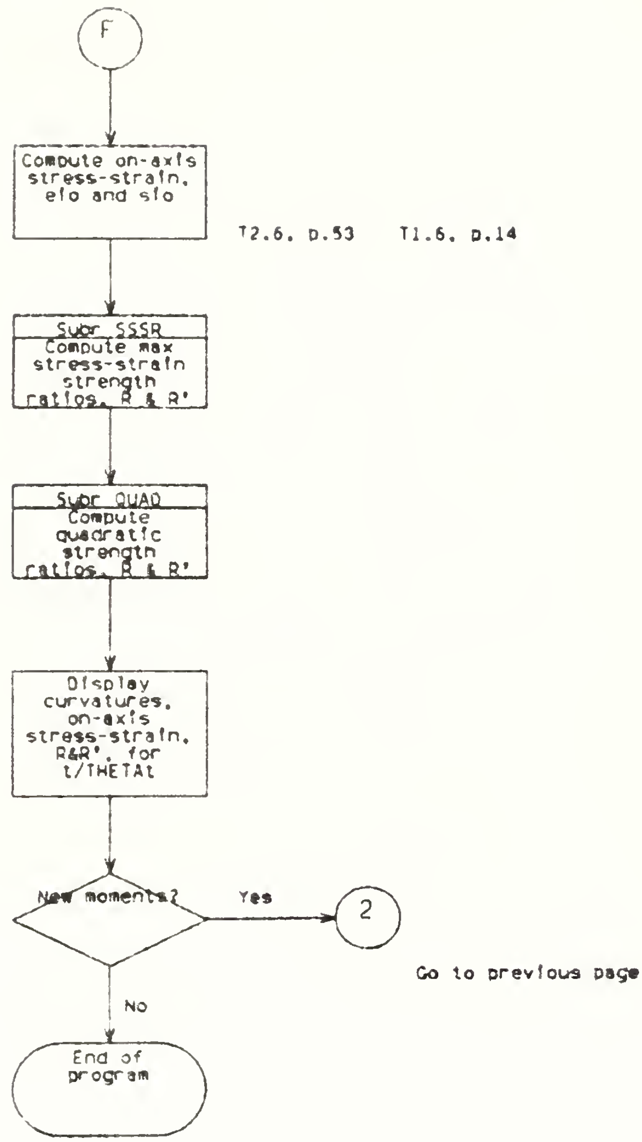

A
Display engineering constants?
Yes
Display Ex, Ey, vx, Es, X, X', Y, Y', S
No
Compute on-axis modulus and compliance: Qij, Sij
eqns (1.9), (1.12) pp.13,15
Compute UiQ's=f(Qxys) i=1-5
eqn (3.15), p.73
Compute on-axis A matrix for single ply Aij=Qij*ho
Compute aij=Aij**-1
Display computed variables?
Yes
Display Qij, Sij, UiQ's, Aij, aij
No
Compute strength parameters Fij and Gij (ij=xys)
Display computed variables?
Yes
Diplay Fij, Fi, Gij, Gi (ij=xys)
No
B


B
Computation of in-plane properties follows...
CORE
Select CORE/NO CORE
NO CORE
Enter n,nc (n=# plies; nc=# equiv core plies)
Enter n (n=# of plies)
h=(n+nc)*ho
h=n*no
Enter tf, index # for ply adjacent core
Let tf = 1
SUBR THETA
Enter THETA(tf), THETA(tf+1), ... THETA(n/2)
SUBR Vf/VfD
Vf=2*ho*Vf
VfD=(h**3)*2/3*VfD
SUBR THETA
Enter THETA(1), THETA(2), ..., THETA(n/2)
zs=nc*ho/h
Volume fraction of core
zs=0
Compute in-plane modulus of laminates, Aij (ij=126)
T4.3, p.124
Compute in-plane compliance (inverse) => aij
matrix inversion
C


C
Compute normalized variables: Aij*=Aij/h aij*=aij*h
Compute effective in-plane engineering constants: Eio, vijo
Display computed variables?
Display Aij, aij, Eio, Aij*, aij*
Input loads: N1, N2, N6
1
Compute in-plane strain variables: eio=f(aij,Ni)
T(4.2), p.121
New load and THETAt from next page.
Enter THETAt, angle of ply to be examined
Compute on-axis strain variables, eio
T2.6, p.53
D


D
Compute on-axis stress variables, sio
T1.6, p.14
Subr SSSR
Compute max stress-strain strength ratios, R & R'
Subr QUAD
Compute quadratic strength ratios, R & R'
Display in-plane strain, on-axis stress-strain, R & R'
New load and THETAt?
Yes
1
Go to previous page
Computation of flexural properties follows ...
hs=(1-zs**3)*h**3/12
See T5.3, p.180
Compute flexural modulus, Dij=f(UiQ,hs,ViD)
T5.3, p.180
E


E
Compute dij
(inverse Dij)
Compute
Dij*=Dij*12/h**3
dij*=dij*h**3/12
Compute
effective
flexural
laminate moduli
Eij, vij
Eqn (5.21), p.177
Display
computed
variables?
Yes
Display Dij,
dij, Eij, Dij*,
dij*
No
Input moments:
M1, M2, M6
2
New moments
(see next page)
Enter index t
and THETAt for
desired ply
Compute
curvatures
ki=f(dij,Mj)
T5.2, p.176
F


F
Compute on-axis stress-strain, eio and sio
T2.6, p.53 T1.6, p.14
Subr SSSR
Compute max stress-strain strength ratios, R & R'
Subr QUAD
Compute quadratic strength ratios, R & R'
Display curvatures, on-axis stress-strain, R&R', for t/THETAt
New moments?
Yes
2
Go to previous page
No
End of program

Appendix B

PROGRAM CODE

```
10 PAGESIZE 16
20 OPTION BASE 1
30 CLEAR @ DISP @ DISP "Do you wish to have a copy of the output on "
40 DISP "a printer?  Y/N"
50 INPUT A$
60 IF UPC$ (A$)="Y" THEN PRINTER IS 701 ELSE PRINTER IS 1
70 CLEAR
80 PRINT @ PRINT "COMPUTATION OF IN-PLANE AND FLEXURAL PROPERTIES OF SYMMETRIC"
90 PRINT "          LAMINATES ON THE HP-87 MICROCOMPUTER" @ PRINT @ PRINT
100 DISP @ DISP @ DISP @ DISP "Initialization of program variables.  Standby."
110 !  Initialize variables, strings, and arrays.
120 INTEGER I,J,t,t1,n,nc,FLAG
130 REAL EX,EY,NUX,ES,X,XP,Y,YP,S,e1o,e2o,e6o,e1f,e2f,e6f,s1f,s2f,s6f
140 REAL H,QXX,QYY,QXY,QSS,SXX,SYY,SXY,SSS,E1o,E2o,v21o,E6o,E1f,E2f,v21f,E6f
150 REAL AXX,AYY,AXY,ASS,axx,ayy,axy,ass
160 REAL FXX,FYY,FXY,FSS,FX,FY,FXYS,GXX,GYY,GXY,GSS,GX,GY,U1Q,U2Q,U3Q,U4Q,U5Q
170 REAL N1,N2,N6,M1,M2,M6,k1,k2,k6,h,ho,zs,hs,p,q,a,b,c,nn,mm,SE,Ie,Re,x
180 REAL V1,V2,V3,V4,V1D,V2D,V3D,V4D,THETA,THETAd,DET
190 REAL exo,eyo,eso,sxo,syo,sso,sto,stopp
200 REAL REPSX,REPSXP,REPSY,REPSYP,REPSS,REPSSP
210 REAL RSIGX,RSIGXP,RSIGY,RSIGYP,RSIGS,RSIGSP
220 DIM A(6,6),a(6,6),AS(6,6),as(6,6),Q(6,6),THETA(50)
230 DIM D(6,6),d(6,6),DS(6,6),ds(6,6)
240 V1,V2,V3,V4,V1D,V2D,V3D,V4D,FLAG=0
250 SE=6894.97543
260 FXYS=-.5
270 FOR I=1 TO 6
280    FOR J=1 TO 6
290       Q(I,J)=0 @ A(I,J)=0 @ AS(I,J)=0 @ a(I,J)=0 @ as(I,J)=0
300       D(I,J)=0 @ DS(I,J)=0 @ d(I,J)=0 @ ds(I,J)=0
310    NEXT J
320 NEXT I
330 GOTO 660
340 CLEAR @ FLAG=1
350 PRINT @ PRINT "SI -> English Units Conversion:  A program 'flag' has been"
360 PRINT "that will key appropriate logic to convert each of the values input"
370 PRINT "automatically in SI units by program READ statements.  If this"
380 PRINT "option is selected, be sure to input 'ho', the laminate thickness,"
390 PRINT "in English units as well."
400 PRINT @ PRINT "Now, press CONTINUE to return to the CRT display of the"
410 PRINT "material selection." @ PRINT @ PRINT
420 PAUSE
```

```
430 GOTO 660
440 PAGESIZE 24 @ CLEAR @ PRINT @ PRINT
450 PRINT "   The LAMINATE program is designed to quickly calculate in-plane"
460 PRINT "and flexural strength and stiffness properties of selected "
470 PRINT "laminates.  The program is interactive and prompts the user for"
480 PRINT "all required input parameters.  Other prompts will request the user"
490 PRINT "to select or skip a display of various modulus and compliance "
500 PRINT "matrices as well as effective engineering constants.  Most other"
510 PRINT "prompts are self explanatory."
520 PRINT
530 PRINT "References:  (a) Tsai, S.W., Hahn, H.T., 'Introduction to Composite"
540 PRINT "                 Materials', TECHNOMIC Publishing Co., c1980."
550 PRINT "             (b) Donaldson, S.L., 'Revised Instructions for TI-59"
560 PRINT "                 Combined Card/Module Calculations for In-Plane and"
570 PRINT "                 Flexural Properties of Symmetric Laminates', Air"
580 PRINT "                 Force Systems Command, June 1982."
590 PRINT @ PRINT "Program written by:"
600 PRINT "LCDR D.R. Ferrell, USN"
610 PRINT "Department of Aeronautics"
620 PRINT "Naval Postgraduate School"
630 PRINT "Monterey, California 93940","(September, 1982)"
640 DISP ,,,"Press CONTINUE"
650 PAUSE
660 PAGESIZE 16 @ CLEAR
670 ! Set key labels for composite material selection display.
680 ON KEY# 1,"T300/5208" GOTO C1
690 ON KEY# 2,"B(4)/5505" GOTO C2
700 ON KEY# 3,"AS/3501" GOTO C3
710 ON KEY# 4,"SP1002" GOTO C4
720 ON KEY# 5,"KV49/EPOXY" GOTO C5
730 ON KEY# 6,"User Def'd" GOTO C6
740 ON KEY# 7,"References" GOTO 440
750 ON KEY# 8,"SI -> ENG" GOTO 340
760 KEY LABEL
770 DISP "  Selection of one of the five composites listed below automatically"
780 DISP "reads appropriate engineering constants and values of compressive,"
790 DISP "tensile, and shear strengths into variable names for later computa-"
800 DISP "tions.  All values are in SI units.  If you anticipate working in"
810 DISP "English units, press the 'SI -> ENG' key.  If you desire to define"
820 DISP "a material not listed here, select 'User Def'd'.  The program will"
830 DISP "then interactively request values for Ex, Ey, vx, Es, X, X', Y,"
840 DISP "Y', and S.  Select 'References' for an explanation of the program"
850 DISP "and a listing of references."
860 GOTO 860
870 ! Set data pointer to read appropriate data string for constants.
880 C1: RESTORE D1 @ GOTO RD
890 C2: RESTORE D2 @ GOTO RD
900 C3: RESTORE D3 @ GOTO RD
910 C4: RESTORE D4 @ GOTO RD
920 C5: RESTORE D5 @ GOTO RD
930 ! READ and DATA statements for the constants.
940 RD: READ COMPOSITE$,EX,EY,NUX,ES,X,XP,Y,YP,S
```

```
950 IF FLAG=0 THEN GOTO 1160
960    EX=EX/SE @ EY=EY/SE @ ES=ES/SE
970    X=X/SE @ XP=XP/SE @ Y=Y/SE @ YP=YP/SE @ S=S/SE
980 GOTO 1160
990 ! DATA statements.  See pages 19 and 292, ref (a).
1000 D1: DATA T300/5208,181000000000,10300000000,.28,7170000000,1500000000,15000
00000,40000000,246000000,68000000
1010 D2: DATA B(4)/5505,204000000000,18500000000,.23,5590000000,1260000000,25000
00000,61000000,202000000,67000000
1020 D3: DATA AS/3501,138000000000,8960000000,.3,7100000000,1447000000,144700000
0,51700000,206000000,93000000
1030 D4: DATA SP1002,38600000000,8270000000,.26,4140000000,1062000000,610000000,
31000000,118000000,72000000
1040 D5: DATA KV49/EPOXY,76000000000,5500000000,.34,2300000000,1400000000,235000
000,12000000,53000000,34000000
1050 C6: CLEAR
1060 PRINT "Input name of the material:"
1070 INPUT COMPOSITE$
1080 PRINT @ PRINT "Input engineering constants:"
1090 PRINT "Ex, Ey, vx, Es"
1100 INPUT EX,EY,NUX,ES
1110 PRINT USING "2(3D.3DE),.4D,3D.3DE" ; EX,EY,NUX,ES
1120 PRINT @ PRINT "Input compressive, tensile, and shear strengths:"
1130 PRINT "X, X', Y, Y' S"
1140 INPUT X,XP,Y,YP,S
1150 PRINT USING "5(3D.3DE)" ; X,XP,Y,YP,S
1160 CLEAR @ PRINT "Selected composite material =) ";COMPOSITE$
1170 PRINT @ PRINT @ PRINT "Input laminate thickness, ho (SI or ENG)."
1180 PRINT @ PRINT @ INPUT ho
1190 PRINT @ PRINT "ho =";ho
1200 WAIT 1000
1210 CLEAR @ DISP @ DISP "Do you wish to see a display of the engineering"
1220 DISP "constants, and the compressive, tensile, and shear contants?"
1230 DISP "   Y/N"
1240 INPUT A$
1250 IF UPC$ (A$)="N" THEN GOTO 1420
1260 CLEAR @ PRINT @ PRINT "***************************************************
**************************" @ PRINT
1270 PRINT "Engineering constants and compressive, tensile, and shear"
1280 PRINT "constants for ";COMPOSITE$
1290 PRINT
1300 PRINT USING "10X,5A,3D.3DE" ; "Ex = ",EX
1310 PRINT USING "10X,5A,X,2D.3DE" ; "Ey = ",EY
1320 PRINT USING "10X,5A,3X,.2D" ; "vx = ",NUX
1330 PRINT USING "10X,5A,2X,D.3DE" ; "Es = ",ES
1340 PRINT @ PRINT USING "11X,4A,4D.3DE" ; "X = ",X
1350 PRINT USING "10X,5A,4D.3DE" ; "X' = ",XP
1360 PRINT USING "11X,4A,2X,2D.3DE" ; "Y = ",Y
1370 PRINT USING "10X,5A,X,3D.3DE" ; "Y' = ",YP
1380 PRINT USING "11X,4A,2X,2D.3DE" ; "S = ",S
```

```
1390 PRINT @ PRINT "****************************************************************
*******************" @ PRINT
1400 DISP "Use the (ROLL) key to view CRT output.",,"Press CONTINUE"
1410 PAUSE
1420 CLEAR @ DISP @ DISP @ DISP "Computation of on-axis modulus and compliance"
1430 DISP "terms.  Standby."
1440 M=1/(1-NUX^2*(EY/EX))
1450 QXX=M*EX @ QYY=M*EY @ QXY=M*NUX*EY @ QSS=ES
1460 SXX=1/EX @ SYY=1/EY @ SXY=-(NUX/EX) @ SSS=1/ES
1470 ! Compute UiQ's, the linear combinations of on-axis moduli (Qij, ij=xys)
1480    U1Q=(3*QXX+3*QYY+2*QXY+4*QSS)/8
1490    U2Q=(QXX-QYY)/2
1500    U3Q=(QXX+QYY-2*QXY-4*QSS)/8
1510    U4Q=(QXX+QYY+6*QXY-4*QSS)/8
1520    U5Q=(QXX+QYY-2*QXY+4*QSS)/8
1530 ! Compute on-axis A matrix for single ply
1540 AXX=QXX*ho @ AYY=QYY*ho @ AXY=QXY*ho @ ASS=QSS*ho
1550 ! Compute inversion of A matrix (aij).  See page 97.
1560  DET=ASS*(AXX*AYY-AXY^2)
1570  axx=AYY*ASS/DET @ ayy=AXX*ASS/DET @ axy=-(AXY*ASS/DET) @ ass=AXX*AYY/DET
1580 DISP @ DISP "Do you wish to see a display of the on-axis Qij's, Sij's"
1590 DISP "UiQ's, Aij's, and aij's?"
1600 DISP "   Y/N"
1610 INPUT A$
1620 IF UPC$ (A$)="N" THEN GOTO 1880
1630 PAGESIZE 24 @ CLEAR
1640 PRINT @ PRINT "****************************************************************
*******************" @ PRINT
1650 PRINT "On-axis Qij's, Sij's, UiQ's, Aij's, and aij's for ";COMPOSITE$
1660 PRINT "(Note:  ij=xys)." @ PRINT
1670 PRINT @ PRINT USING "19X,2A,3D.2DE,2X,D.4DE,6X,A" ; "( ",QXX,QXY,"0"
1680 PRINT USING "5X,18A,11X,2D.3DE,6X,A" ; "on-axis Qij = (",QYY,"0"
1690 PRINT USING "19X,A,27X,D.4DE" ; "(",QSS
1700 PRINT
1710 PRINT USING "19X,2A,D.4DE,2X,2D.3DE,6X,A" ; "( ",SXX,SXY,"0"
1720 PRINT USING "5X,18A,11X,2D.3DE,6X,A" ; "on-axis Sij = (",SYY,"0"
1730 PRINT USING "19X,A,27X,3D.2DE" ; "(",SSS
1740 PRINT @ PRINT USING "13X,6A,2D.4DE" ; "U1Q = ",U1Q
1750 PRINT USING "13X,6A,2D.4DE" ; "U2Q = ",U2Q
1760 PRINT USING "13X,6A,2D.4DE" ; "U3Q = ",U3Q
1770 PRINT USING "13X,6A,2D.4DE" ; "U4Q = ",U4Q
1780 PRINT USING "13X,6A,2D.4DE" ; "U5Q = ",U5Q
1790 PRINT @ PRINT USING "19X,2A,2D.3DE,2X,.5DE,6X,A" ; "( ",AXX,AXY,"0"
1800 PRINT USING "5X,18A,11X,D.4DE,6X,A" ; "on-axis Aij = (",AYY,"0"
1810 PRINT USING "19X,A,27X,.5DE" ; "(",ASS
1820 PRINT @ PRINT USING "19X,2A,2D.3DE,2X,3D.2DE,6X,A" ; "( ",axx,axy,"0"
1830 PRINT USING "5X,18A,11X,3D.2DE,6X,A" ; "on-axis aij = (",ayy,"0"
1840 PRINT USING "19X,A,27X,4D.DE" ; "(",ass
1850 PRINT @ PRINT "****************************************************************
*******************" @ PRINT
1860 DISP "Use (ROLL) key to view CRT output.",,"Press CONTINUE"
```

```
1870 PAUSE
1880 CLEAR @ PAGESIZE 16 @ DISP @ DISP @ DISP
1890 DISP "Computation of strength parameters in strain and stress space."
1900 DISP "Standby."
1910 FXX=1/(X*XP) @ FYY=1/(Y*YP) @ FXY=FXYS*SQR (FXX*FYY) @ FSS=1/S^2
1920 FX=1/X-1/XP @ FY=1/Y-1/YP
1930 GXX=FXX*QXX^2+2*FXY*QXX*QXY+FYY*QXY^2
1940 GYY=FXX*QXY^2+2*FXY*QXY*QYY+FYY*QYY^2
1950 GXY=FXX*QXX*QXY+FXY*(QXX*QYY+QXY^2)+FYY*QXY*QYY
1960 GSS=FSS*QSS^2
1970 GX=FX*QXX+FY*QXY
1980 GY=FX*QXY+FY*QYY
1990 DISP @ DISP
2000 DISP "Do you wish to see a display of strength parameters in stress"
2010 DISP "space, Fij, and strain space, Gij?"
2020 DISP "   Y/N"
2030 INPUT A$
2040 IF UPC$ (A$)="N" THEN GOTO 2250
2050 CLEAR @ PAGESIZE 24 @ CLEAR
2060 PRINT @ PRINT "*************************************************************
********************" @ PRINT
2070 PRINT "Strength parameters in stress space, Fij, and strain space, Gij."
2080 PRINT "for ";COMPOSITE$;" (Note:  ij=xys)." @ PRINT @ PRINT
2090 PRINT USING "17X,2A,.5DE,2X,2D.3DE,6X,A" ; "( ",FXX,FXY,"0"
2100 PRINT USING "11X,7A,14X,3D.2DE,6X,A" ; "Fij = (",FYY,"0"
2110 PRINT USING "17X,A,27X,3D.2DE" ; "(",FSS    .
2120 PRINT
2130 PRINT USING "12X,5A,2D.3DE" ; "Fx = ",FX
2140 PRINT USING "12X,5A,2D.3DE" ; "Fy = ",FY
2150 PRINT @ PRINT @ PRINT
2160 PRINT USING "17X,2A,2D.3DE,2X,2D.3DE,6X,A" ; "( ",GXX,GXY,"0"
2170 PRINT USING "11X,7A,14X,2D.3DE,6X,A" ; "Gij = (",GYY,"0"
2180 PRINT USING "17X,A,27X,2D.3DE" ; "(",GSS
2190 PRINT
2200 PRINT USING "12X,5A,D.4DE" ; "Gx = ",GX
2210 PRINT USING "12X,5A,D.4DE" ; "Gy = ",GY
2220 PRINT @ PRINT "*************************************************************
********************" @ PRINT
2230 DISP "Use the (ROLL) key to view CRT output.",,"Press CONTINUE"
2240 PAUSE
2250 PAGESIZE 16 @ CLEAR @ PRINT
2260 PRINT @ PRINT "*************************************************************
********************"
2270 PRINT "*********************************************************************
************" @ PRINT
2280 PRINT "The program will now compute in-plane and flexural properties of"
2290 PRINT "laminates specified by the user.  Either CORE or NO CORE laminates"
2300 PRINT "can be specified and any number of plies defined.  The user will"
2310 PRINT "note that this program takes a 'brute force' approach by request-"
2320 PRINT "ing an entry for each ply.  This method allows simpler program "
2330 PRINT "code, ensures fewer errors, and enhances accuracy."
```

```
2340 PRINT @ PRINT "************************************************************
********************"
2350 PRINT "********************************************************************
************" @ PRINT
2360 PRINT "In-plane computations follow..."
2370 PRINT @ PRINT "Will the laminate contain CORE or NO CORE?"
2380 PRINT "   C/NC => END LINE" @ PRINT @ PRINT
2390 INPUT A$
2400 IF UPC$ (A$)="C" THEN GOTO 2560
2410 CLEAR @ PRINT @ PRINT "NO CORE laminate:  Enter 'n', the total number"
2420 PRINT "of plies, surface to surface."
2430 PRINT "   n = ?"
2440 INPUT n
2450 PRINT @ PRINT "n =";n @ PRINT @ PRINT
2460 h=n*ho ! Thickness of NO CORE laminate.
2470 PRINT @ PRINT @ PRINT "NO CORE laminate thickness, h =";h
2480 PRINT @ PRINT @ PRINT "Now enter the ply orientation of each ply:"
2490 PRINT "THETA(1), THETA(2), ... , THETA(n/2)"
2500 PRINT "*** --> FROM CENTER TO OUTER SURFACE <-- ***  (IMPORTANT!)"
2510 PRINT @ PRINT @ PRINT
2520 ti=1
2530 GOSUB THETA
2540 zs=0 ! Volume fraction of core.
2550 GOTO 2800
2560 CLEAR @ PRINT @ PRINT "CORE laminate:  Enter 'n', the total number of"
2570 PRINT "laminate plies, and 'nc', the total number of equivalent core"
2580 PRINT "plies that define its thickness, surface to surface."
2590 PRINT "   n,nc = ?"
2600 INPUT n,nc
2610 PRINT @ PRINT "n =";n;"   nc =";nc
2620 WAIT 1000 @ h=(n+nc)*ho ! Thickness of CORE laminate.
2630 PRINT @ PRINT @ PRINT "CORE laminate thickness, h =";h
2640 WAIT 1000 @ CLEAR
2650 PRINT @ PRINT
2660 PRINT "Counting outward from the center of the laminate, enter an "
2670 PRINT "integer number 'ti' (t initial) that represents the consecutive"
2680 PRINT "index number of the ply adjacent to the core.  (For instance,"
2690 PRINT "if the core is a total of 4ho thick, count 2 equivalent ply layers"
2700 PRINT "from the center so that ti=3)."
2710 PRINT "   ti = ?"
2720 INPUT ti
2730 PRINT @ PRINT @ PRINT "ti =";ti
2740 WAIT 1000 @ PRINT
2750 PRINT @ PRINT "Now enter the ply orientation, in degrees, for each ply:"
2760 PRINT "THETA(ti), THETA(ti+1) ... , THETA(n/2)."
2770 PRINT "*** --> CENTER MOST PLY TO OUTER SURFACE PLY <-- ***  (IMPORTANT)"
2780 GOSUB THETA
2790 zs=nc*ho/h ! Volume fraction of core.
2800 CLEAR @ DISP @ DISP @ DISP "Computation of in-plane properties.  Standby."
2810 ! Computation of in-plane modulus of laminates.
2820    A(1,1)=U10*(n*ho)+V1*U20+V2*U30
2830    A(2,2)=U10*(n*ho)-V1*U20+V2*U30
```

```
2840    A(1,2)=U4Q*(n*ho)-V2*U3Q
2850    A(6,6)=U5Q*(n*ho)-V2*U3Q
2860    A(1,6)=V3*U2Q/2+V4*U3Q
2870    A(2,6)=V3*U2Q/2-V4*U3Q
2880 ! Computation of in-plane compliance of laminates (inversion of A(i,j))
2890 DET=A(1,1)*A(2,2)*A(6,6)+2*A(1,2)*A(2,6)*A(1,6)-A(2,2)*A(1,6)^2-A(6,6)*A(1,
2)^2-A(1,1)*A(2,6)^2
2900    a(1,1)=(A(2,2)*A(6,6)-A(2,6)^2)/DET
2910    a(2,2)=(A(1,1)*A(6,6)-A(1,6)^2)/DET
2920    a(1,2)=(A(1,6)*A(2,6)-A(1,2)*A(6,6))/DET
2930    a(6,6)=(A(1,1)*A(2,2)-A(1,2)^2)/DET
2940    a(1,6)=(A(1,2)*A(2,6)-A(2,2)*A(1,6))/DET
2950    a(2,6)=(A(1,2)*A(1,6)-A(1,1)*A(2,6))/DET
2960 ! Computation of normalized in-plane modulus and compliance
2970 FOR I=1 TO 6
2980    FOR J=1 TO 6
2990        AS(I,J)=A(I,J)/h
3000        as(I,J)=a(I,J)*h
3010    NEXT J
3020 NEXT I
3030 ! Computation of effective in-plane engineering constants.
3040    E1o=1/(a(1,1)*h) ! Longitudinal modulus
3050    E2o=1/(a(2,2)*h) ! Transverse modulus
3060    E6o=1/(a(6,6)*h) ! Shear modulus
3070    v21o=-(a(1,2)/a(1,1)) ! Poisson's ratio
3080 DISP @ DISP @ DISP "Do you wish to see a display of effective in-plane "
3090 DISP "engineering constants, the in-plane stiffness matrix (Aij)"
3100 DISP "and its inverse (aij), and the normalized versions of these"
3110 DISP "matrices (Aij* and aij*)?"
3120 DISP "   Y/N"
3130 INPUT A$
3140 IF UPC$ (A$)="N" THEN GOTO 3430
3150 PAGESIZE 24 @ CLEAR @ PRINT
3160 PRINT @ PRINT "*****************************************************************
*******************" @ PRINT
3170 PRINT "In-plane parameters:  Aij's, aij's, engineering constants, and"
3180 PRINT "normalized Aij*'s and aij*'s for ";COMPOSITE$;"  (Note:  ij=126)"
3190 PRINT @ PRINT
3200 PRINT USING "19X,2A,2D.3DE,2X,D.4DE,2X,D.4DE" ; "( ",A(1,1),A(1,2),A(1,6)
3210 PRINT USING "4X,17A,13X,2D.3DE,2X,D.4DE" ; "in-plane Aij = (",A(2,2),A(2,6)

3220 PRINT USING "19X,A,27X,D.4DE" ; "(",A(6,6)
3230 PRINT
3240 PRINT USING "19X,2A,2D.3DE,2X,D.4DE,2X,D.4DE" ; "( ",a(1,1),a(1,2),a(1,6)
3250 PRINT USING "4X,17A,13X,2D.3DE,2X,D.4DE" ; "in-plane aij = (",a(2,2),a(2,6)

3260 PRINT USING "19X,A,27X,D.4DE" ; "(",a(6,6)
3270 PRINT
3280 PRINT USING "13X,6A,D.4DE" ; "E1o = ",E1o
3290 PRINT USING "13X,6A,D.4DE" ; "E2o = ",E2o
3300 PRINT USING "12X,7A,.5D" ; "v21o = ",v21o
```

```
3310 PRINT USING "13X,6A,D.4DE" ; "E6o = ",E6o
3320 PRINT
3330 PRINT USING "19X,2A,D.4DE,2X,D.4DE,2X,D.4DE" ; "( ",AS(1,1),AS(1,2),AS(1,6)

3340 PRINT USING "3X,17A,14X,D.4DE,2X,D.4DE" ; "in-plane Aij* = (",AS(2,2),AS(2,
6)
3350 PRINT USING "19X,A,27X,D.4DE" ; "(",AS(6,6)
3360 PRINT
3370 PRINT USING "19X,2A,D.4DE,2X,D.4DE,2X,D.4DE" ; "( ",as(1,1),as(1,2),as(1,6)

3380 PRINT USING "3X,17A,14X,D.4DE,2X,D.4DE" ; "in-plane aij* = (",as(2,2),as(2,
6)
3390 PRINT USING "19X,A,27X,D.4DE" ; "(",as(6,6)
3400 PRINT @ PRINT "************************************************************
*******************" @ PRINT
3410 DISP "Use (ROLL) key to view CRT output.",,"Press CONTINUE"
3420 PAUSE
3430 CLEAR @ PAGESIZE 16
3440 DISP "It will now be necessary to input the loads, N1, N2, and N6."
3450 DISP "Consider two options:"
3460 DISP "    Case (a):  Input selective unit loads to determine"
3470 DISP "               maximum loading allowable."
3480 DISP "    Case (b):  Input actual loading to determine strain"
3490 DISP "               invariants and strength ratios."
3500 DISP "(The program operates the same in either case.  It is up to the "
3510 DISP "user to interpret the output properly)."
3520 PRINT @ PRINT @ PRINT "Input loads N1,N2,N6" @ PRINT @ PRINT
3530 INPUT N1,N2,N6
3540 PRINT @ PRINT "N1 =";N1;"   N2 =";N2;"   N6 =";N6
3550 WAIT 1000
3560 ! Compute the in-plane strain variables, e1o, e2o, e6o. (T4.2, p.121)
3570    e1o=a(1,1)*N1+a(1,2)*N2+a(1,6)*N6
3580    e2o=a(1,2)*N1+a(2,2)*N2+a(2,6)*N6
3590    e6o=a(1,6)*N1+a(2,6)*N2+a(6,6)*N6
3600 PRINT @ PRINT @ PRINT @ CLEAR
3610 PRINT @ PRINT "Now, enter THETAt, the orientation of the ply"
3620 PRINT "to be examined (in degrees)."
3630 PRINT "   THETAt = ?" @ PRINT @ PRINT
3640 INPUT THETAd
3650 PRINT @ PRINT "THETAt =";THETAd
3660 WAIT 1000
3670 THETAt=THETAd*PI /180
3680 CLEAR @ DISP @ DISP @ DISP "Computation of in-plane properties.  Standby"
3690 ! Compute the on-axis strain variable, exo, eyo, eso, for the given ply.
3700 ! T2.6, p.53
3710    p=(e1o+e2o)/2 @ q=(e1o-e2o)/2 @ r=e6o/2
3720    mm=COS (2*THETAt) @ nn=SIN (2*THETAt)
3730       exo=p+q*mm+r*nn
3740       eyo=p-q*mm-r*nn
3750       eso=-(2*q*nn)+2*r*mm
3760 ! Compute the on-axis stress variables, sxo, syo, sso, for the given ply.
```

```
3770 ! T1.6, p.14
3780       sxo=QXX*exo+QXY*eyo
3790       syo=QXY*exo+QYY*eyo
3800       sso=QSS*eso
3810 GOSUB SSSR  ! Go subr to compute the stress-strain strength ratios, R&R'
3820 GOSUB QUAD  ! Go subr to compute the quadratic strength ratios.
3830   sto=Rq/h @ stopp=Rqp/h
3840 CLEAR @ PAGESIZE 24 @ CLEAR @ PRINT
3850 PRINT @ PRINT "************************************************************
*******************" @ PRINT
3860 PRINT USING "10X,23A,2D.3DE" ; "in-plane strain: e1o = ",e1o
3870 PRINT USING "27X,6A,D.4DE" ; "e2o = ",e2o
3880 PRINT USING "27X,6A,D.4DE" ; "e6o = ",e6o
3890 PRINT @ PRINT "For THETAt =";THETAd;" ....  (";COMPOSITE$;")" @ PRINT
3900 PRINT USING "20X,22A,D.4DE" ; "on-axis strain: exo = ",exo
3910 PRINT USING "36X,6A,2D.3DE" ; "eyo = ",eyo
3920 PRINT USING "36X,6A,D.4DE" ; "eso = ",eso
3930 PRINT
3940 PRINT USING "20X,22A,2D.3DE" ; "on-axis stress: sxo = ",sxo
3950 PRINT USING "36X,6A,2D.3DE" ; "syo = ",syo
3960 PRINT USING "36X,6A,D.4DE" ; "sso = ",sso
3970 PRINT @ PRINT
3980 PRINT USING "10X,15A,8X,A,11X,2A" ; "strength ratios","R","R'"
3990 PRINT
4000 PRINT USING "15X,10A,4X,D.DDE,3X,D.DDE" ; "max strain ",Re,Rep
4010 PRINT USING "15X,10A,4X,D.DDE,3X,D.DDE" ; "max stress ",Rs,Rsp
4020 PRINT USING "15X,10A,4X,D.DDE,3X,D.DDE" ; "quadratic  ",Rq,Rqp
4030 PRINT
4040 PRINT USING "20X,24A,D.4DE" ; "average stresses: sto = ",sto
4050 PRINT USING "37X,7A,D.4DE" ; "sto' = ",stopp
4060 PRINT USING "30X,22A" ; "(=f(quadratic R & R'))"
4070 PRINT @ PRINT "************************************************************
*******************" @ PRINT
4080 DISP "Use (ROLL) key to view CRT output.",,"Press CONTINUE"
4090 PAUSE
4100 CLEAR @ PAGESIZE 16
4110 DISP "Do you wish to compute in-plane properties for"
4120 DISP "a new load and THETAt?"
4130 DISP "   Y/N"
4140 INPUT A$
4150 IF UPC$ (A$)="N" THEN GOTO 4200
4160 DISP @ DISP "Enter new N1,N2,N6."
4170 INPUT N1,N2,N6
4180 PRINT @ PRINT @ PRINT "New load:  N1 =";N1;"   N2 =";N2;"   N6 =";N6
4190 WAIT 1000 @ GOTO 3560
4200 CLEAR @ PRINT
4210 PRINT @ PRINT "************************************************************
*******************"
4220 PRINT "*******************************************************************
************" @ PRINT
4230 PRINT "The program will now compute flexural properties for the laminate"
```

```
4240 PRINT "defined during the in-plane definitions.  Properties calculated"
4250 PRINT "include the flexural stiffness matrix (Dij), the flexural compli-"
4260 PRINT "ance matrix (dij), effective flexural laminate moduli (Eif), and"
4270 PRINT "the normalized versions of stiffness matrices (Dij* and dij*)."
4280 PRINT @ PRINT "*****************************************************************
*******************"
4290 PRINT "*******************************************************************
***********"
4300 DISP @ DISP ,,,"Press CONTINUE"
4310 PAUSE
4320 CLEAR @ DISP @ DISP @ DISP
4330 DISP "Computation of flexural properties.  Standby."
4340 hs=(1-zs^3)*h^3/12
4350 ! Compute flexural modulus (T5.3, p.181)
4360    D(1,1)=U1Q*hs+V1D*U2Q+V2D*U3Q
4370    D(2,2)=U1Q*hs-V1D*U2Q+V2D*U3Q
4380    D(1,2)=U4Q*hs-V2D*U3Q
4390    D(6,6)=U5Q*hs-V2D*U3Q
4400    D(1,6)=U2Q*V3D/2+V4D*U3Q
4410    D(2,6)=U2Q*V3D/2-V4D*U3Q
4420 ! Compute flexural compliance (inverse of Dij)
4430    DET=D(1,1)*D(2,2)*D(6,6)+2*D(1,2)*D(2,6)*D(1,6)-D(2,2)*D(1,6)^2-D(6,6)*D
(1,2)^2-D(1,1)*D(2,6)^2
4440    d(1,1)=(D(2,2)*D(6,6)-D(2,6)^2)/DET
4450    d(2,2)=(D(1,1)*D(6,6)-D(1,6)^2)/DET
4460    d(1,2)=(D(1,6)*D(2,6)-D(1,2)*D(6,6))/DET
4470    d(6,6)=(D(1,1)*D(2,2)-D(1,2)^2)/DET
4480    d(1,6)=(D(1,2)*D(2,6)-D(2,2)*D(1,6))/DET
4490    d(2,6)=(D(1,2)*D(1,6)-D(1,1)*D(2,6))/DET
4500 ! Compute normalized versions of Dij and dij.
4510 FOR I=1 TO 6
4520    FOR J=1 TO 6
4530       DS(I,J)=D(I,J)*12/h^3
4540       ds(I,J)=d(I,J)*h^3/12
4550    NEXT J
4560 NEXT I
4570 ! Compute effective flexural laminate moduli.
4580    E1f=12/(h^3*d(1,1))
4590    E2f=12/(h^3*d(2,2))
4600    E6f=12/(h^3*d(6,6))
4610    v21f=-(d(1,2)/d(1,1))
4620 DISP @ DISP
4630 DISP "Do you wish to see a display of flexural modulus and compliance"
4640 DISP "matrices (Dij and dij), effective flexural laminate moduli, and"
4650 DISP "the normalized versions of the modulus and compliance matrices?"
4660 DISP "   Y/N"
4670 INPUT A$
4680 IF UPC$ (A$)="N" THEN GOTO 4970
4690 PAGESIZE 24 @ CLEAR @ PRINT
4700 PRINT @ PRINT "*****************************************************************
********************" @ PRINT
```

```
4710 PRINT "Flexural properties Dij, dij, effective flexural engineering"
4720 PRINT "constants, and the normalized Dij* and dij*.  (Note: ij=126)"
4730 PRINT
4740 PRINT USING "19X,2A,D.4DE,2X,.5DE,2X,D.4DE" ; "( ",D(1,1),D(1,2),D(1,6)
4750 PRINT USING "4X,16A,14X,D.4DE,2X,D.4DE" ; "flexural Dij = (",D(2,2),D(2,6)
4760 PRINT USING "19X,A,27X,D.4DE" ; "(",D(6,6)
4770 PRINT
4780 PRINT USING "19X,2A,D.4DE,2X,D.4DE,2X,D.4DE" ; "( ",d(1,1),d(1,2),d(1,6)
4790 PRINT USING "4X,16A,14X,D.4DE,2X,D.4DE" ; "flexural dij = (",d(2,2),d(2,6)
4800 PRINT USING "19X,A,27X,D.4DE" ; "(",d(6,6)
4810 PRINT
4820 PRINT USING "13X,6A,D.4DE" ; "E1f = ",E1f
4830 PRINT USING "13X,7A,D.4DE" ; "E2f = ",E2f
4840 PRINT USING "12X,9A,.5D" ; "v21f = ",v21f
4850 PRINT USING "13X,6A,D.4DE" ; "E6f = ",E6f
4860 PRINT
4870 PRINT USING "19X,2A,D.4DE,2X,D.4DE,2X,D.4DE" ; "( ",DS(1,1),DS(1,2),DS(1,6)

4880 PRINT USING "3X,17A,14X,D.4DE,2X,D.4DE" ; "flexural Dij* = (",DS(2,2),DS(2,
6)
4890 PRINT USING "19X,A,27X,D.4DE" ; "(",DS(6,6)
4900 PRINT
4910 PRINT USING "19X,2A,D.4DE,2X,D.4DE,2X,D.4DE" ; "( ",ds(1,1),ds(1,2),ds(1,6)

4920 PRINT USING "3X,17A,14X,D.4DE,2X,D.4DE" ; "flexural dij* = (",ds(2,2),ds(2,
6)
4930 PRINT USING "19X,A,27X,D.4DE" ; "(",ds(6,6)
4940 PRINT @ PRINT "*************************************************************
*******************" @ PRINT
4950 DISP "Use (ROLL) key to view CRT output.",,"Press CONTINUE"
4960 PAUSE
4970 PAGESIZE 16 @ CLEAR
4980 DISP "It will now be necessary to input moments M1, M2, and M6."
4990 DISP "Consider two options."
5000 DISP "    Case (a):  Input selective unit moments to determine the"
5010 DISP "               max loading allowable."
5020 DISP "    Case (b):  Input actual moments to determine strength ratios"
5030 DISP "               and curvatures."
5040 DISP "(The program operates the same in either case.  It is up to the"
5050 DISP "user to properly interpret the results)."
5060 PRINT @ PRINT "Input moments M1,M2,M6" @ PRINT @ PRINT
5070 INPUT M1,M2,M6
5080 PRINT @ PRINT "M1 =";M1;"   M2 =";M2;"   M6 =";M6
5090 WAIT 1000
5100 CLEAR @ PRINT @ PRINT
5110 PRINT "Now, enter the index number, t, and the orientation, THETAt,"
5120 PRINT "of the ply to be examined."
5130 PRINT "   t, THETAt = ?" @ PRINT @ PRINT @ PRINT
5140 INPUT t,THETAd
5150 PRINT @ PRINT "t =";t;"   THETAt =";THETAd
5160 WAIT 1000
```

```
5170 THETAt=THETAd*PI /180
5180 CLEAR @ DISP @ DISP @ DISP "         Standby"
5190 ! Computation of curvatures, ki.  (T5.2, p.176)
5200    k1=d(1,1)*M1+d(1,2)*M2+d(1,6)*M6
5210    k2=d(1,2)*M1+d(2,2)*M2+d(2,6)*M6
5220    k6=d(1,6)*M1+d(2,6)*M2+d(6,6)*M6
5230       e1o=k1*t*ho ! actually e1f; called e1o for subr QUAD
5240       e2o=k2*t*ho
5250       e6o=k6*t*ho
5260          e1f=e1o
5270          e2f=e2o
5280          e6f=e6o
5290 ! Compute off-axis compliance for stress calculations.
5300    V1=ho*COS (2*THETAt)
5310    V2=ho*COS (4*THETAt)
5320    V3=ho*SIN (2*THETAt)
5330    V4=ho*SIN (4*THETAt)
5340       A(1,1)=U1Q*ho+V1*U2Q+V2*U3Q
5350          Q(1,1)=A(1,1)/ho
5360       A(2,2)=U1Q*ho-V1*U2Q+V2*U3Q
5370          Q(2,2)=A(2,2)/ho
5380       A(1,2)=U4Q*ho-V2*U3Q
5390          Q(1,2)=A(1,2)/ho
5400       A(6,6)=U5Q*ho-V2*U3Q
5410          Q(6,6)=A(6,6)/ho
5420       A(1,6)=U2Q*V3/2+V4*U3Q
5430          Q(1,6)=A(1,6)/ho
5440       A(2,6)=U2Q*V3/2-V4*U3Q
5450          Q(2,6)=A(2,6)/ho
5460             s1f=Q(1,1)*e1f+Q(1,2)*e2f+Q(1,6)*e6f
5470             s2f=Q(1,2)*e1f+Q(2,2)*e2f+Q(2,6)*e6f
5480             s6f=Q(1,6)*e6f+Q(2,6)*e2f+Q(6,6)*e6f
5490 ! Compute on-axis strain for R/R' calculations.
5500 ! (T2.6, p.53)
5510    p=(e1o+e2o)/2 @ q=(e1o-e2o)/2 @ r=e6o/2
5520    mm=COS (2*THETAt) @ nn=SIN (2*THETAt)
5530       exo=p+q*mm+r*nn
5540       eyo=p-q*mm-r*nn
5550       eso=-(2*q*nn)+2*r*mm
5560 ! Compute on-axis stress for R/R' calculations.
5570       sxo=QXX*exo+QXY*eyo
5580       syo=QXY*exo+QYY*eyo
5590       sso=QSS*eso
5600 GOSUB SSSR
5610 GOSUB QUAD
5620    sto=6*Rq/h^2 @ stopp=6*Rqp/h^2
5630 CLEAR @ PAGESIZE 24 @ CLEAR
5640 PRINT @ PRINT "************************************************************
********************" @ PRINT
5650 PRINT USING "10X,16A,D.4DE" ; "curvature, k1 = ",k1
5660 PRINT USING "21X,5A,D.4DE" ; "k2 = ",k2
```

```
5670 PRINT USING "21X,5A,D.4DE" ; "k6 = ",k6
5680 PRINT @ PRINT "For t =";t;"and THETAt =";THETAd @ PRINT
5690 PRINT USING "4X,23A,D.4DE" ; "flex'l strains, e1f = ",e1f
5700 PRINT USING "20X,6A,D.4DE" ; "e2f = ",e2f
5710 PRINT USING "20X,6A,D.4DE" ; "e6f = ",e6f
5720 PRINT
5730 PRINT USING "3X,23A,D.4DE" ; "flex'l stresses, s1f = ",s1f
5740 PRINT USING "20X,6A,D.4DE" ; "s2f = ",s2f
5750 PRINT USING "20X,6A,D.4DE" ; "s6f = ",s6f
5760 PRINT
5770 PRINT USING "15A,8X,A,11X,2A" ; "strength ratios","R","R'"
5780 PRINT
5790 PRINT USING "5X,10A,4X,D.DDE,3X,D.DDE" ; "max strain ",Re,Rep
5800 PRINT USING "5X,10A,4X,D.DDE,3X,D.DDE" ; "max stress ",Rs,Rsp
5810 PRINT USING "5X,10A,4X,D.DDE,3X,D.DDE" ; "quadratic  ",Rq,Rqp
5820 PRINT
5830 PRINT USING "20X,24A,D.4DE" ; "average stresses: sto = ",sto
5840 PRINT USING "37X,7A,D.4DE" ; "sto' = ",stopp
5850 PRINT USING "30X,22A" ; "(=f(quadratic R & R'))"
5860 PRINT @ PRINT "****************************************************************
********************" @ PRINT
5870 DISP "Use (ROLL) key to view CRT output.",,"Press CONTINUE"
5880 PAUSE
5890 CLEAR @ PAGESIZE 16 @ DISP @ DISP @ DISP
5900 DISP "Do you wish to compute a new set of moments, M1,M2,M6, index t,"
5910 DISP "and orientation, THETAt?  (NO will terminate program operation)."
5920 DISP "   Y/N"
5930 INPUT A$
5940 IF UPC$ (A$)="N" THEN GOTO 6000
5950 PRINT @ PRINT @ PRINT "Input new loads M1,M2,M6" @ PRINT @ PRINT
5960 INPUT M1,M2,M6
5970 PRINT @ PRINT "New moments:  M1 =";M1;"   M2 =";M2;"   M6 =";M6
5980 WAIT 1000
5990 GOTO 5100
6000 PRINT @ PRINT "End of program.  Thank you."
6010 END
6020 !
6030 !
6040 THETA: ! Subroutine to enter THETA's for calculation of Vi's and ViD's.
6050 FOR t=ti TO n/2+ti-1
6060    PRINT @ PRINT "   THETA(";t;") = ?" @ PRINT
6070    INPUT THETA(t)
6080    PRINT ,THETA(t)
6090    THETA(t)=THETA(t)*PI /180
6100    GOSUB Vi
6110    GOSUB ViD
6120 NEXT t
6130 x=2*ho
6140 V1=x*V1 @ V2=x*V2 @ V3=x*V3 @ V4=x*V4
6150 x=2/3*ho^3
6160 V1D=x*V1D @ V2D=x*V2D @ V3D=x*V3D @ V4D=x*V4D
6170 RETURN
```

```
6180 !
6190    Vi:
6200       V1=V1+COS (2*THETA(t))
6210       V2=V2+COS (4*THETA(t))
6220       V3=V3+SIN (2*THETA(t))
6230       V4=V4+SIN (4*THETA(t))
6240    RETURN
6250 !
6260    ViD:
6270       x=t^3-(t-1)^3
6280       V1D=V1D+COS (2*THETA(t))*x
6290       V2D=V2D+COS (4*THETA(t))*x
6300       V3D=V3D+SIN (2*THETA(t))*x
6310       V4D=V4D+SIN (4*THETA(t))*x
6320    RETURN
6330 !
6340 !
6350 QUAD: ! Transformation of quadratic strength parameters in strain space
6360 !       in multiple angle functions.  T7.6a, p.298
6370    mm=COS (THETAt) @ nn=SIN (THETAt)
6380 G11=GXX*mm^4+GYY*nn^4+GXY*2*mm^2*nn^2+GSS*4*mm^2*nn^2
6390 G22=GXX*nn^4+GYY*mm^4+GXY*2*mm^2*nn^2+GSS*4*mm^2*nn^2
6400 G12=GXX*mm^2*nn^2+GYY*mm^2*nn^2+GXY*(mm^4+nn^4)-GSS*4*mm^2*nn^2
6410 G66=GXX*mm^2*nn^2+GYY*mm^2*nn^2-GXY*2*mm^2*nn^2+GSS*(mm^2-nn^2)^2
6420 G16=GXX*mm^3*nn-GYY*mm*nn^3+GXY*(mm*nn^3-mm^3*nn)+GSS*2*(mm*nn^3-mm^3*nn)
6430 G26=GXX*mm*nn^3-GYY*mm^3*nn+GXY*(mm^3*nn-mm*nn^3)+GSS*2*(mm^3*nn-mm*nn^3)
6440 G1=GX*mm^2+GY*nn^2 ! T7.6b, p.298
6450 G2=GX*nn^2+GY*mm^2
6460 G6=GX*mm*nn-GY*mm*nn
6470 a=G11*e1o^2+G22*e2o^2+2*G12*e1o*e2o+G66*e6o^2+2*G16*e1o*e6o+2*G26*e2o*e6o
6480 b=G1*e1o+G2*e2o+G6*e6o
6490 c=-1
6500 Rq=(-b+SQR (b^2-4*a*c))/(2*a)
6510 Rqp=ABS ((-b-SQR (b^2-4*a*c))/(2*a))
6520 RETURN
6530 !
6540 !
6550 SSSR: ! Subroutine to compute max stress-strain R and R'
6560 Res=S/ABS (eso*ES)
6570 IF exo>0 THEN Rex=X/(exo*EX) ELSE Rex=XP/ABS (exo*EX)
6580   IF eyo>0 THEN Rey=Y/(eyo*EY) ELSE Rey=YP/ABS (eyo*EY)
6590     IF Rex<Rey THEN Re=Rex ELSE Re=Rey
6600       IF Res<Re THEN Re=Res
6610   IF exo<0 THEN Rex=X/ABS (exo*EX) ELSE Rex=XP/(exo*EX)
6620     IF eyo<0 THEN Rey=Y/ABS (eyo*EY) ELSE Rey=YP/(eyo*EY)
6630       IF Rex<Rey THEN Rep=Rex ELSE Rep=Rey
6640         IF Res<Rep THEN Rep=Res
6650 Rss=S/ABS (sso)
6660 IF sxo>0 THEN Rsx=X/sxo ELSE Rsx=XP/ABS (sxo)
6670   IF syo>0 THEN Rsy=Y/syo ELSE Rsy=YP/ABS (syo)
6680     IF Rsx<Rsy THEN Rs=Rsx ELSE Rs=Rsy
```

```
6690        IF Rss<Rs THEN Rs=Rss
6700    IF sxo<0 THEN Rsx=X/ABS (sxo) ELSE Rsx=XP/sxo
6710      IF syo<0 THEN Rsy=Y/ABS (syo) ELSE Rsy=YP/syo
6720        IF Rsx<Rsy THEN Rsp=Rsx ELSE Rsp=Rsy
6730          IF Rss<Rsp THEN Rsp=Rss
6740 RETURN
6750 END
```

LIST OF REFERENCES

1. Materials Laboratory (AFWAL/MLBM), Air Force Wright Aeronautical Laboratories, AFWAL-TR-82, Revised Instructions for TI-59 Combined Card/Module Calculations for In-Plane and Flexural Properties of Symmetric Laminates, by S.L. Donaldson, June 1982.

2. Tsai, S.W., Introduction to Composite Materials, Technomic Publishing Co., 1980.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0142 Naval Postgraduate School Monterey, California 93940	2
3.	Department Chairman, Code 31 Department of Aeronautical Engineering Naval Postgraduate School Monterey, California 93940	1
4.	Dr. Stephen W. Tsai AFWAL/MLBM Wright-Patterson AFB, Ohio 45433	35
5.	LCDR Dennis R. Ferrell, USN Carrier Airborne Early Warning Training Squadron ONE HUNDRED TEN (RVAW-110) NAS Miramar San Diego, California 92145	2
6.	Dr. Milton H. Bank Aviation Safety Programs Code 034BT Naval Postgraduate School Monterey, California 93940	1
7.	LCDR Patrick D. Sullivan Naval Postgraduate School, SMC 1768 Monterey, California 93940	1